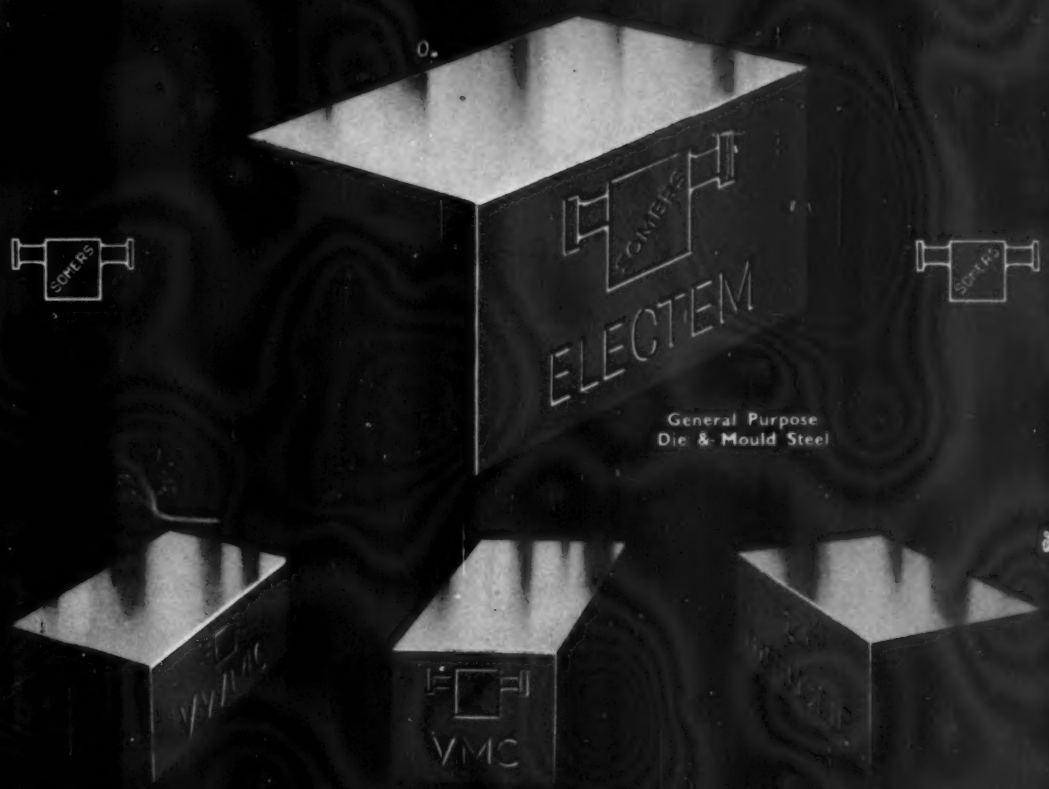
metallurgical atment

Vol. 28 : No. 183 MAY, 1961 Price 2/6

DIE STEELS



General Purpose
Die & Mould Steel

Chromium/Vanadium
Tungsten/Molybdenum
Hot Working & Forging
Die Steel

Chromium/Molybdenum/
Vanadium
Aluminium Extrusion &
Pressure Die Casting Steel

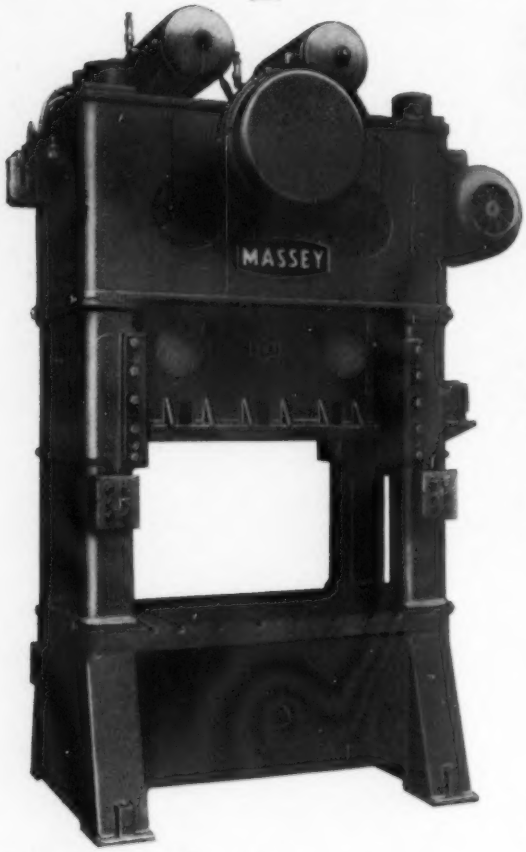
Nickel/Chromium
Molybdenum
Backing Die & Hot
Working Steel

Walter Somers Limited

HAYWOOD FORGE · HALES OWEN · NR. BIRMINGHAM Telephone: Hales Owen 1185

MASSEY

MULTI-PURPOSE PRESSES for the drop forging industry



WIDE RAM TYPE for

PREFORMING—BENDING
TRIMMING—PUNCHING
SETTING—SIZING

- ★ Available in sizes from 100 to 1,000 tons, this specially designed multi-purpose press enables preforming, setting and straightening to be carried out in addition to trimming and piercing operations.
- ★ Electrically driven, with transmission by alloy steel double helical gears.
- ★ Comprehensive lubrication system automatically interlocked with main press drive.
- ★ Frame of maximum strength with large diameter tie bolts shrunk into position.
- ★ Air-operated friction clutch fully protected against overload

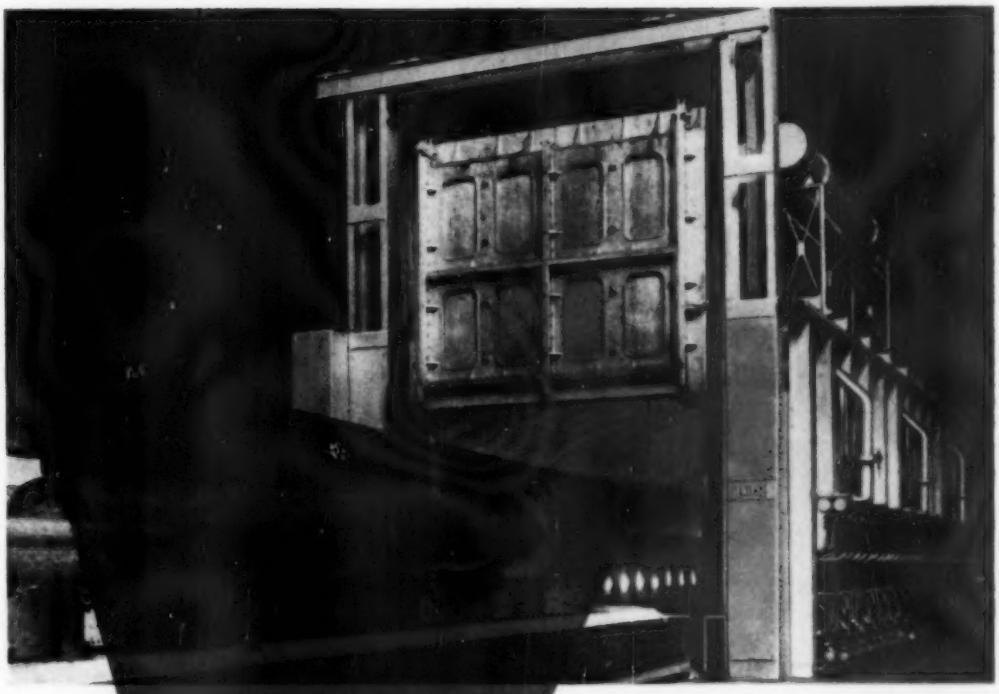
CENTENARY
1861-1961

100-Ton Wide Ram Trimming and Setting Press

MASSEY DESIGNS INCLUDE: *Steam and Compressed Air Hammers, Pneumatic Power Hammers, Friction Drop Hammers, Double-Acting Steam and Compressed Air Drop Hammers, Counterblow Hammers, Forging Presses, Ute Rollers, Trimming Presses, Tyre Fixing Rolls.*

B. & S. MASSEY LTD. OPENSHAW · MANCHESTER · ENGLAND

MAKERS OF THE WORLD'S GREATEST RANGE OF FORGING AND DROP FORGING PLANT



Town's Gas Fired
Bogie Type
Heat Treatment
Furnace

The illustration shows one of a pair of Bogie Hearth Furnaces, 50 feet long by 10 feet wide, supplied to William Beardmore & Company Limited, Glasgow. Specifically designed and zoned for extended accurate heat treatment of specialised materials.

We specialise in the design and construction of :—

Open Hearth Furnaces

Soaking Pits of all types

Continuous Multi-zone Bloom and Slab Re-heating Furnaces

Continuous Bogie type Ingot and Slab Heating Furnaces

Furnaces for Aluminium Melting, Coil Annealing and Slab Re-heating

Forge and Heat Treatment Furnaces

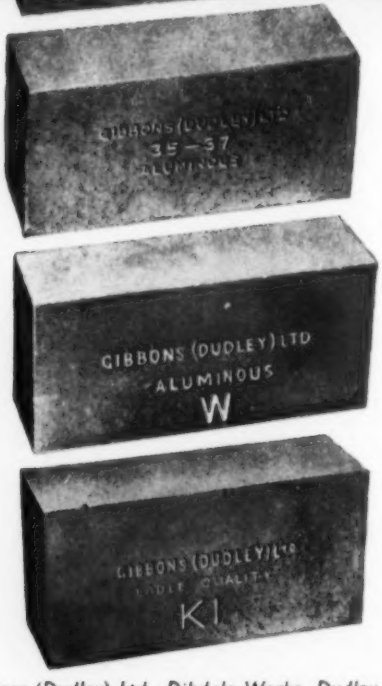
Stress Relieving Furnaces

Shipyard Plate and Bar Furnaces

Modern Lime Burning Kilns

PRIEST

PRIEST FURNACES LIMITED · LONGLANDS · MIDDLESBROUGH also at KELHAM ISLAND WORKS · SHEFFIELD 3



Quality Production

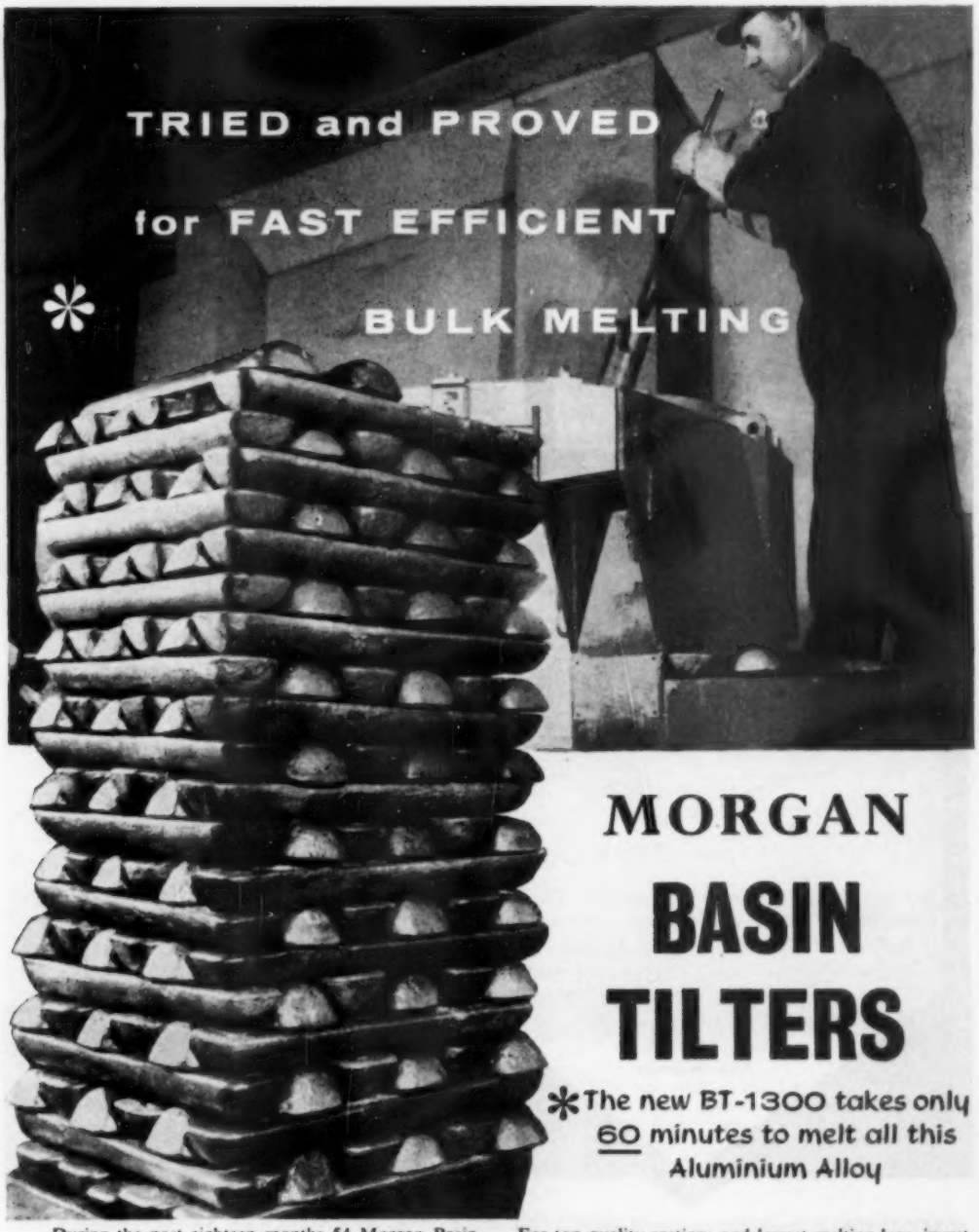
Behind the up-to-date methods of manufacture by which Gibbons Refractories are made, lie a hundred years of experience and research at the Gibbons works, in the development of furnace linings of the highest heat-resisting qualities.

GIBBONS

SUPERIOR REFRACTORIES

H.T.I · ALUMINOUS · SILICA · FIREBRICK
SILLIMANITE

Gibbons (Dudley) Ltd., Dibdale Works, Dudley, Worcs.



MORGAN

BASIN TILTERS

*The new BT-1300 takes only 60 minutes to melt all this Aluminium Alloy

During the past eighteen months 54 Morgan Basin Tilters have been installed in modern foundries for fast and economical bulk melting of a wide range of high quality aluminium or copper based alloys.

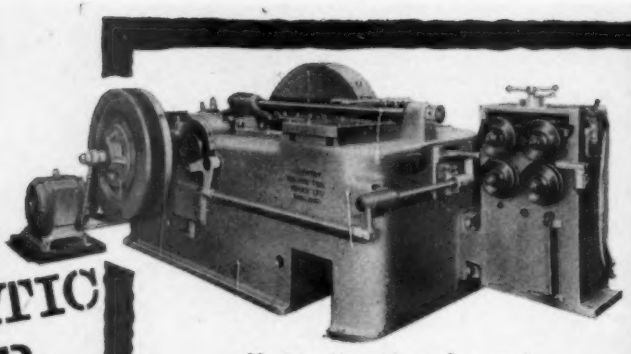
For top quality castings and lowest melting loss, invest in the most flexible of all bulk melters. Ask for a demonstration, with your own metal if preferred, at the Battersea Test Foundry.

MORGANITE CRUCIBLE LIMITED, NORTON WORKS, WOODBURY LANE, WORCESTER. Tel: Worcester 26691 Telex: 33191
A Member of The Morgan Crucible Group.

F54A

COVMAC

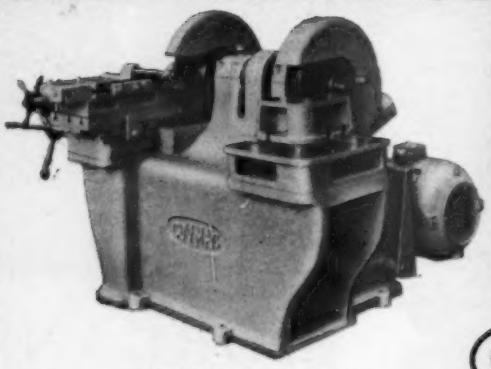
AUTOMATIC FORGER



No. 2 machine with guards removed

The stock is placed between the rolls and is then fed through the dies to the workstop. The die then closes, cutting off the stock to the required length, and delivers it to the heading position. The heading tool then completes the forging, which falls down the chute and is taken away by conveyor.

The Automatic Forger can be supplied in several sizes and for making balls of up to and including 4-in. diameter.



No. 3 machine illustrated

These machines are made in three sizes. The smallest handles bars up to 2-in. diameter. The largest size, as illustrated, takes bars up to 4-in. diameter. They are an invaluable asset to any forging or drop stamping plant.

We also make nine sizes of Standard Upsetting Machines to take bars from ¾-in. to 6-in. diameter

COVMAC

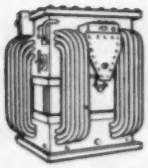
HOT MILLER

COVENTRY MACHINE TOOL WORKS LTD

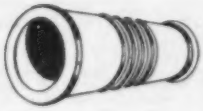
GRANTHAM RD. HALIFAX ENGLAND

Phone: Halifax 3234/5 'Grams': Covmac Halifax

OVERSEAS AGENTS:—AUSTRALIA: Gilbert Lodge & Co., Ltd., 386 Harris Street, Ultimo, Sydney, N.S.W. CANADA: Williams & Wilson Ltd., 544 Inspector Street, Montreal. FRANCE: Societe Anonyme Alfred Herbert, 1 and 3 Rue du Delta, Paris (9e). HOLLAND: Eameijer & Co., Oosterkade 24, Rotterdam, C. INDIA: Alfred Herbert (India) Ltd., 13/3 Strand Road, P.O.B. 681, Calcutta, 1. NEW ZEALAND: Gilbert Lodge & Co., Ltd., Head Office: 55 Station Road, P.O.B. 12-063, Penrose, Auckland, S.E.6, N.Z., also at Christchurch and Wellington. PAKISTAN: Guest, Keen & Nettlefolds in Pakistan Ltd., P.O.B. 819, Bank of India Buildings (3rd Floor), Bunder Road, Karachi. SOUTH AFRICA AND RHODESIA: Hubert Davies & Co., Ltd., Hudaco House, 7 Rissik Street, Johannesburg. SPAIN: Gumuzio S.A., Gran Via 48, Apartado 920, Bilbao. KENYA, UGANDA, TANGANYIKA & ZANZIBAR: Len Cooper Ltd., P.O.B. 3796, Nairobi, Kenya.



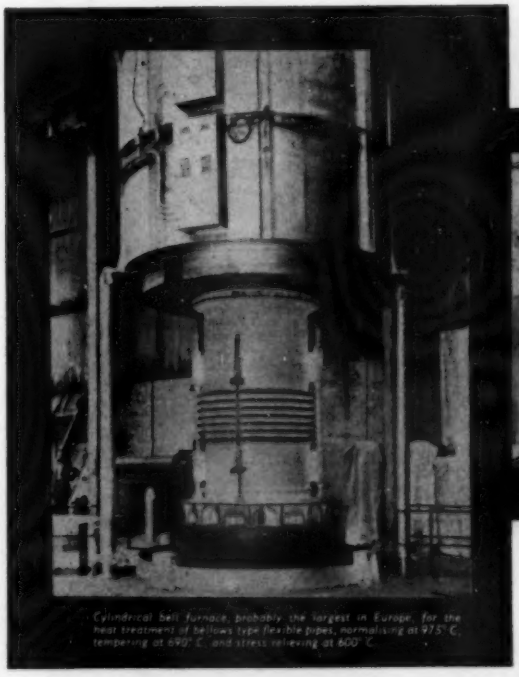
from transformers

to bellows 

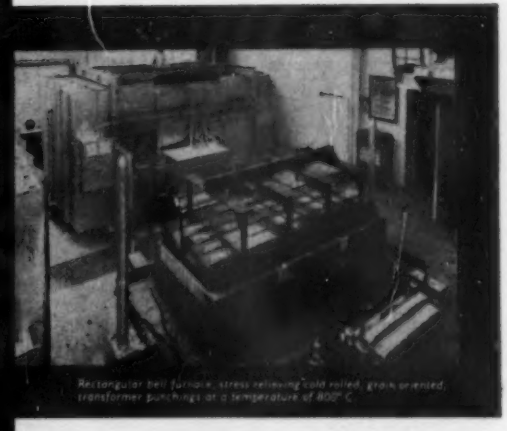
the relief of stresses demands

EFCO

BELL TYPE FURNACES



Cylindrical bell furnace, probably the largest in Europe, for the heat treatment of bellows type flexible pipes, normalising at 975° C, tempering at 690° C, and stress relieving at 600° C.



Rectangular bell furnace, stress relieving cold rolled, grain oriented, transformer punchings at a temperature of 800° C.

When you need to heat treat ferrous or non-ferrous metals, in strip or wire or fabricated form, in rectangular or cylindrical furnaces, in controlled atmosphere or in vacuum — choose an Efco Bell.

EFCO BEST OF THE WORLD'S FURNACE DESIGNS

EFCO FURNACES LIMITED

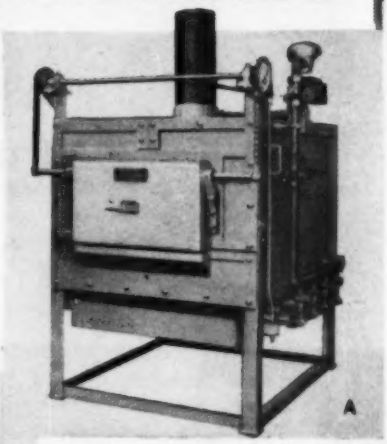
QUEENS ROAD, WEYBRIDGE, SURREY · Weybridge 3091

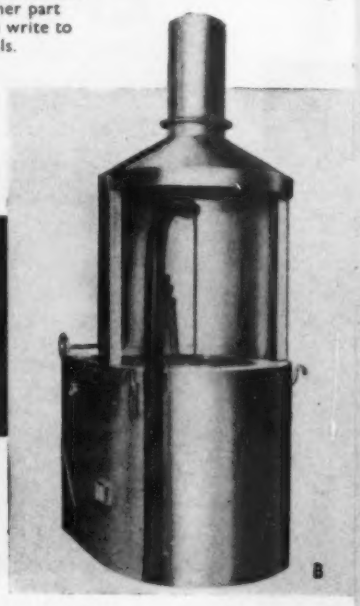
Associated with Electro-Chemical Engineering Co. Ltd.

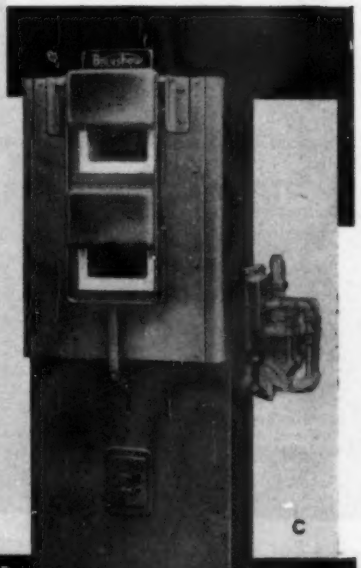
MAP/M 3078

NEW STANDARDS
in tool room heat treatment

Brayshaw Engineers and Technicians are constantly engaged in an intensive research and product development programme designed to maintain our leadership in the manufacture of new furnace equipment of proven dependability and accuracy in widely diverse applications. The products illustrated are just a few examples from our extensive range.
If you would like information on these or any other part of our range please write to us for further details.


A


B


C

What the illustrations show:

A.—'Hynor' Oven Furnace.
B.—Liquid Bath Furnace.
C.—Twin Chambered High Speed Steel Furnace.

Brayshaw FURNACES LTD.
BELLE VUE WORKS · MANCHESTER
Tel. EAST 1046 GRAMS HARDENING, MANCHESTER
SHEFFIELD OFFICE
84 BLONK ST., SHEFFIELD 3 TEL. No. 22409
LONDON OFFICE
232 BISHOPSGATE E.C.2 TEL. BIS 3575-6

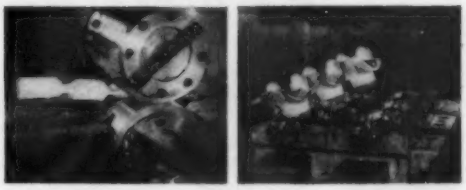
REDUCEROLL + MAXIPRES = Modern Forging!

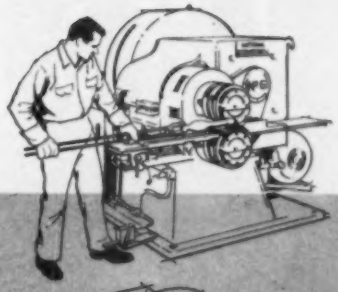
Modern forge plants around the world are using the method shown at right:

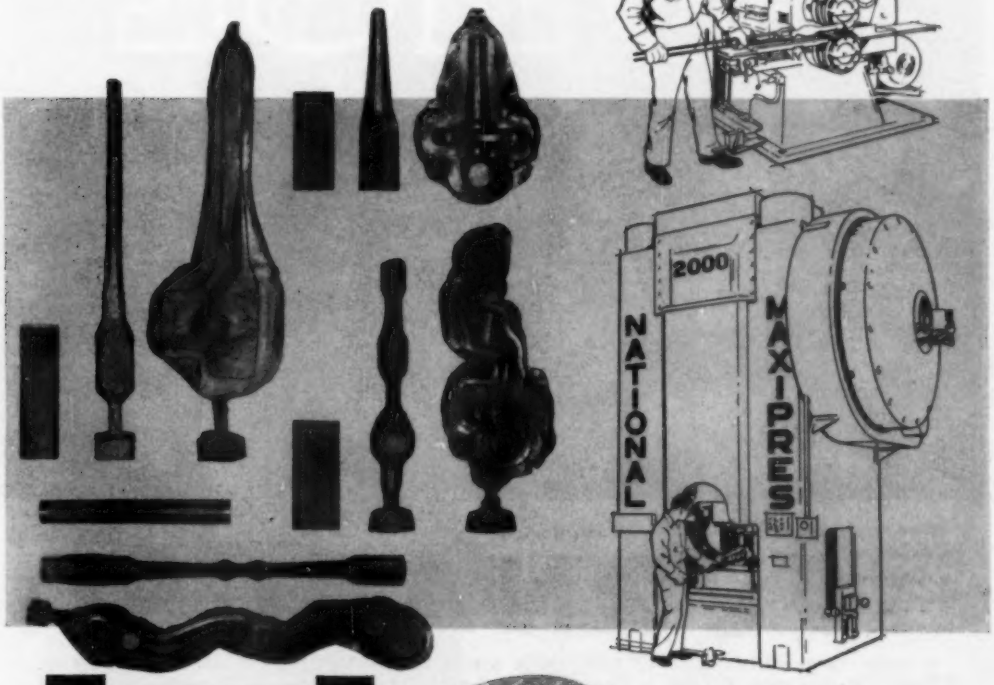
1. Prepare forging blanks in Reducerolls;
2. Finish forge in Maxipresses on the same heat.

Cost of making these forgings, and others, reduces by *one third* (even more!) thanks to modern engineering, latest-design equipment and proven methods.

Bring your prints or forgings to Tiffin or Nurnberg. Let's discuss your plans for automatic or manual forging, but without obligation.





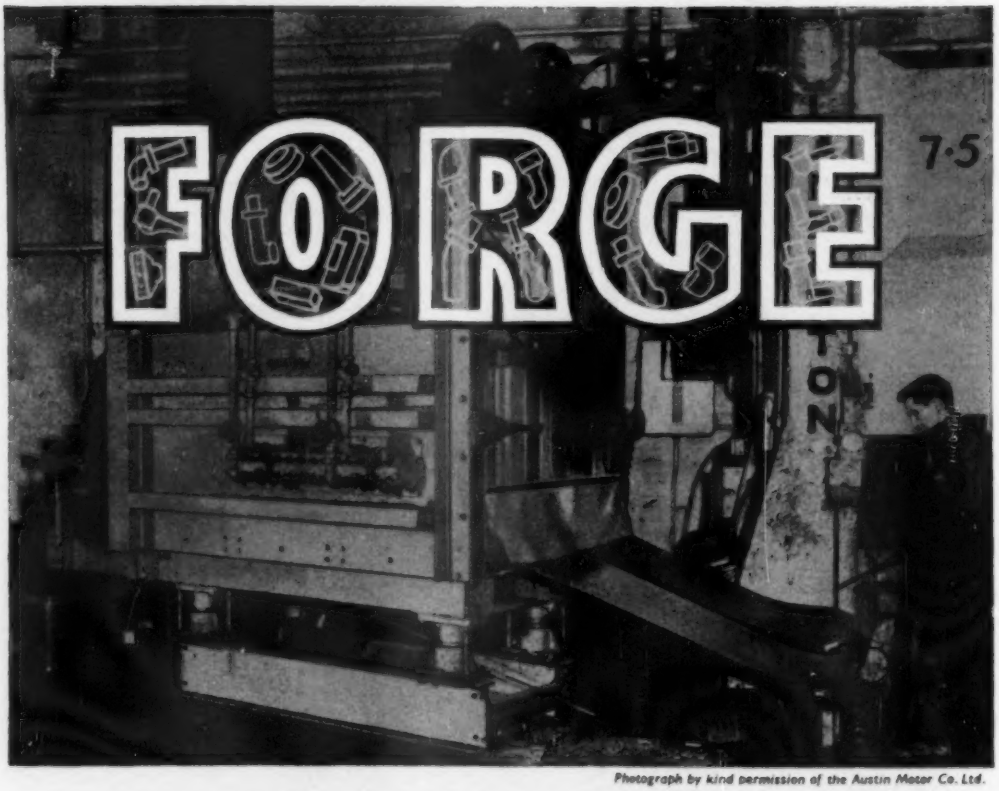


THE NATIONAL MACHINERY CO TIFFIN, OHIO, U.S.A.

J.G. KAYSER G.M.B.H. MASCHINENFABRIK NURNBERG

THERMIC

Mechanised



Photograph by kind permission of the Austin Motor Co. Ltd.

FURNACES

A wide range of standard or tailor-made mechanised forge furnaces is available, Pusher Type - Rotary Hearth Type - Conveyorised Bar End Heating, with GGC scale-free heating system or fired by gas or oil. The photograph above illustrates a small Thermic Magazine Feed Pusher furnace fired by CC Burners. Output: 7-cwts. of small billets per hour.

Thermic Equipment & Engineering Co. Ltd.

(Subsidiary Company of Gibbons Bros. Limited, Dudley)

SALMON STREET, PRESTON TELEPHONE : PRESTON 56254/5 • TELEGRAMS : THERMIC-PRESTON

The New

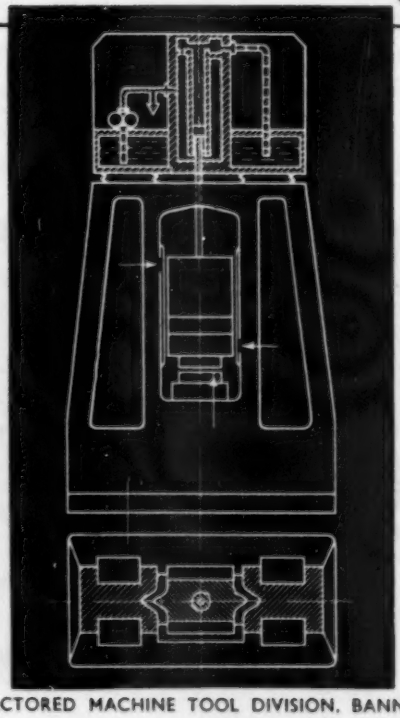
EUMUCO

LEVERKUSEN—GERMANY

PRECISION HAMMER

is a short stroke downward pressure hammer with oil-hydraulic rocker drive.
It was developed for mass production of precision forged components and is a natural addition to the Eumuco range of chain hammers of smaller size up to approx. 10 tons.
The experience gained in double shift operation over a period of more than a year has proved that the aim in designing this hammer has been realized.

of MONOBLOC design



ELECTRIC INDIVIDUAL DRIVE no compressed air.
OILHYDRAULIC ROCKER DRIVE WITH DOWNWARD PRESSURE EFFECT, high efficiency (approx. 75%) without additional cooling by water or oil. Operating medium: non-inflammable hydraulic fluid or hydraulic oil.
Highly durable, unbreakable SHORT, BEND-RESISTING PISTON ROD.
ACCURATE, WEAR-RESISTING TUP GUIDE in the form of hardened and ground adjustable guide faces of great width and length.
LARGE CLAMPING AREAS for protecting the tup and anvil block insert, suitable also for taking die holders.
MONOBLOC DESIGN of the hammer superstructure, anvil block, column and upper cross piece form a single compact rigid steel casting, without any faces subject to wear or connecting pieces, but an anvil block with a large machined bearing face.
SIMPLE OPERATION by electric pedal switch control and universal programme control.

WICKMAN LIMITED

FACTORED MACHINE TOOL DIVISION, BANNER LANE, COVENTRY Telephone : Tile Hill 65231

SST P30

ETHER
LIMITED

'XACTROL'
POTENTIOMETERS

PATENTS APPLIED FOR

—for indicating, recording and controlling any process variable!

For the
accurate measurement of
TEMPERATURE · STRAIN
SPEED · RESISTANCE
PRESSURE · pH · FLOW
CONDUCTIVITY
and other variables

FROM
£126
DELIVERED

SERIES 2000
Single-point Potentiometer Recording Controllers

Type 2000: Two-position on/off control

Type 2001: Anticipatory control

Type 2002: Proportioning (electrical) control

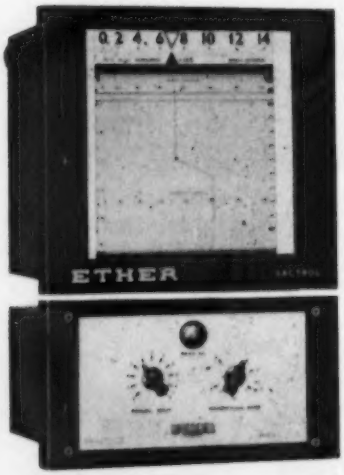
Type 2003: Three-position control

Type 2004: Programme control

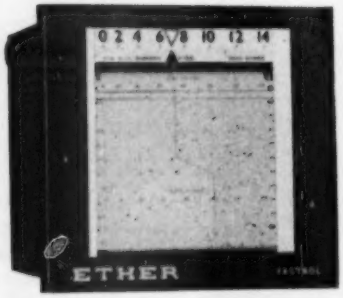
Type 2005: Proportioning (motorised) control

SPECIAL FEATURES:

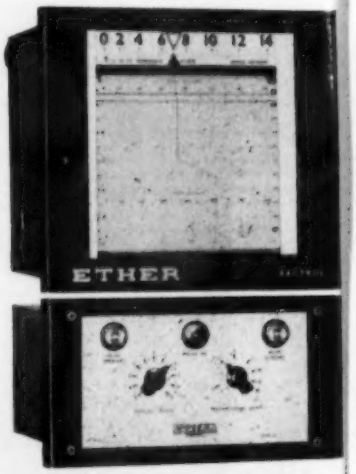
- Interruption of mains supply to instrument automatically shuts down furnace
- 6" calibrated scale
- Standard ranges: 2mV—100mV span; other ranges to order. Changed by plug-in printed-circuit unit
- Standard pen speed: 2 secs. across chart; 1 sec. or 4 secs. also available
- Chart life: 1 month at 1 inch per hr.



Type 2002
Proportioning (electrical) control



Type 2000
Two-position on/off control



Type 2005
Proportioning (motorised) control

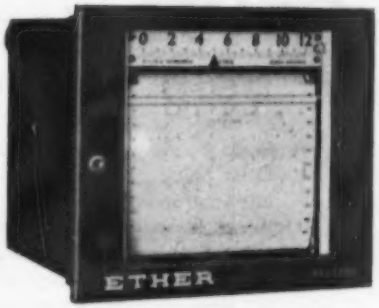
*** SIMPLICITY OF DESIGN * EASIER RANGE CHANGING**
*** EASIER SERVICING AND INSPECTION**

SERIES 2050
Multi-point Potentiometer Recorders

Type 2052: Two-point record

Type 2053: Three-point record

Type 2056: Six-point record



SPECIAL FEATURES:

- Balancing motor totally de-energised throughout printing and indexing cycles
- Simplified printing mechanism
- 6" calibrated scale
- Standard ranges: 5mV—100mV span; other ranges to order. Changed by plug-in printed-circuit unit
- Pen speed: 2 secs. across chart
- Printing speed: 6 secs. per point
- Chart life: 1 month at 1 inch per hour

SERIES 2500
Single-point Potentiometer Indicating Controllers

Type 2500: Two-position on/off control

Type 2501: Anticipatory control

Type 2502: Proportioning (electrical) control

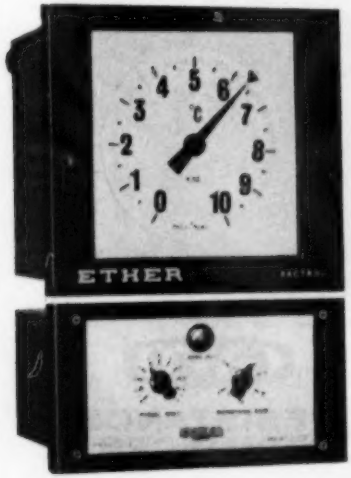
Type 2503: Three-position control

Type 2504: Programme control

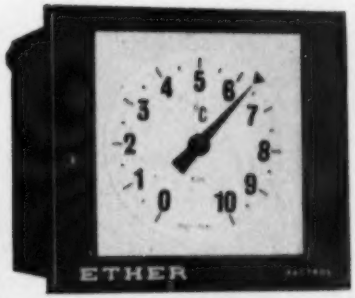
Type 2505: Proportioning (motorised) control

SPECIAL FEATURES:

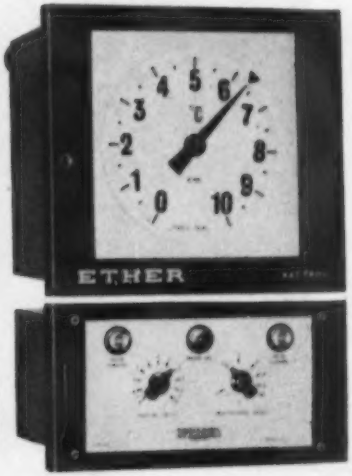
- Interruption of mains supply to instrument automatically shuts down furnace
- 18" calibrated scale
- Bold easy-to-read scale and pointer
- Standard ranges: 5mV—100mV span; other ranges to order. Changed by plug-in printed-circuit unit
- Response speed: 2 secs. across scale



Type 2502
Proportioning (electrical) control



Type 2500
Two-position on/off control



Type 2505
Proportioning (motorised) control

Illustrated leaflets of all 'Xactrol' Potentiometers, from: ETHER LTD.
TYBURN ROAD, ERDINGTON, BIRMINGHAM, 24 : : East 0276-8
CAXTON WAY, STEVENAGE, HERTS : : Stevenage 2110-7

ETHER LIMITED

GWB Electric Annealing Furnaces help step up brass strip output

Earle, Bourne and Co. Ltd., a part of the Delta Metal Co., have been suppliers of tubes and rolled metals since 1875. Among recent development projects they have installed four new heat-treatment furnaces complete with heavy-duty steelworks-type turntable charging machine and loading tables.

The furnaces were designed and built by GWB. Each has a heating chamber 20 ft. long x 5 ft. wide x 3 ft. 6 in. high rated at 342 kW in three zones, and designed for maximum operating temperature of 750°C. Two of the furnaces are also equipped with reduced rating input control for stress relieving applications.

At the present time, the furnaces are operating 24 hours a day on brass strip annealing, work that mostly had to be sub-contracted before. The new furnaces complete an up-to-date and well-organised production line which will considerably step up brass strip output and ensure better deliveries for Earle Bourne's many customers.

G.W.B. FURNACES LIMITED (BOILER DIVISION), DUDLEY, WORCESTERSHIRE. TEL: DUDLEY 55455
Associated with Gibbons Bros. Limited and Wild-Barfield Electric Furnaces Limited

GWB/280

★
36" TYPE 23 R H EXTRACTOR FOR RECLAIMING CUTTING OILS AND COMPOUNDS FROM SWARF

BROADBENT *PLANNED* SWARF DISPOSAL

cuts production costs

by efficiently reclaiming cutting oils and compounds with BROADBENT CENTRIFUGAL OIL EXTRACTORS, and by leaving cleaner scrap which demands higher prices and reduces transport costs

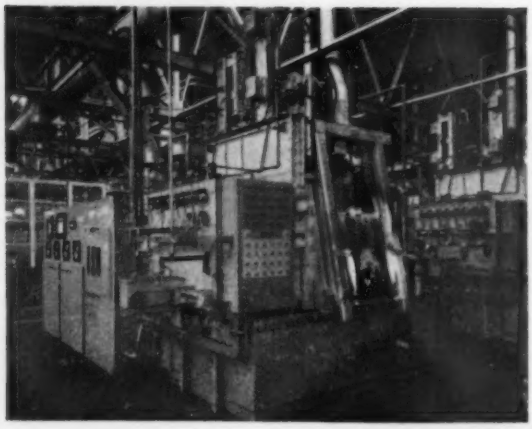
keeps factories cleaner

by eliminating oil soaked floors and at the same time keeping swarf clear of both machines and operators

★ Write for publication S2/5110

THOMAS BROADBENT & SONS LTD

CENTRAL IRONWORKS, HUDDERSFIELD Phone: 5520-5 Grams: "BROADBENT" Huddersfield



The "Allcase" Furnaces illustrated form part of a battery of fully-automatic sequence and programme controlled Furnaces used for Gas Carburising, Carbonitriding, and Reheating of various automobile components.

the versatile "ALLCASE" furnace

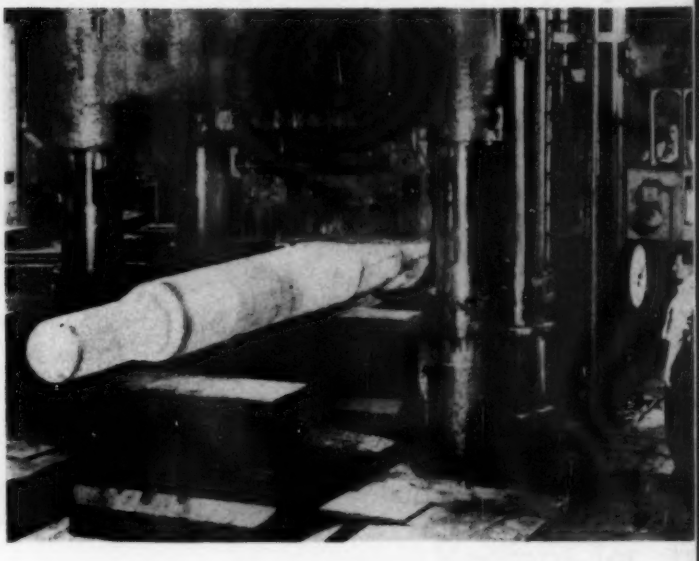
Two "Allcase" Furnaces at the works of a leading motor manufacturer, used for carburizing and carbonitriding steering and other parts, requiring various case compositions and depths. The hearth area of each furnace is 3' 0" x 2' 0" with 1' 6" permissible depth of charge, and is designed to accommodate gross charge weights varying from 900 lb. at 750°C. to 500 lb. at 950°C.

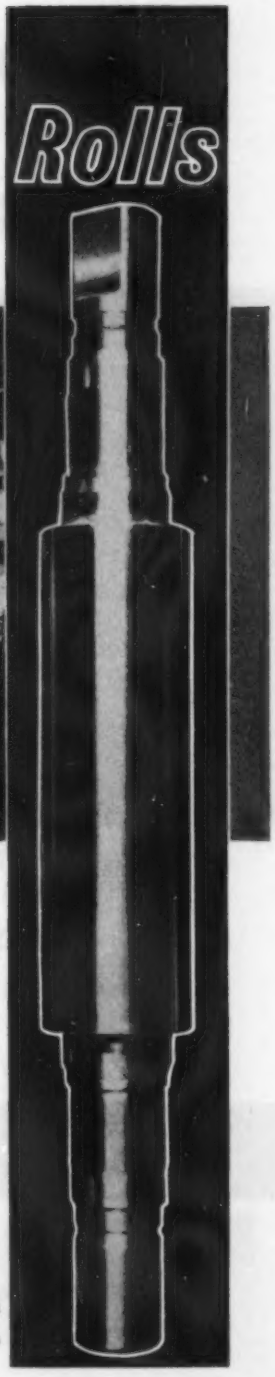
PROCESSES: With an operating temperature range of 1,400 to 1,750°F. the following controlled atmosphere processes can be carried out.

1—Gas Carburizing. 2—Hot Oil Marquenching. 3—Clean Hardening. 4—Dry Cyaniding or Carbonitriding. 5—Carbon Restoration. 6—Homogeneous Carburizing. 7—Clean Annealing.

BRITISH FURNACES LTD.
CHESTERFIELD
ASSOCIATED WITH SURFACE COMBUSTION CORPORATION, TOLEDO, U.S.A.

FIRTH BROWN
Forged Steel Rolls





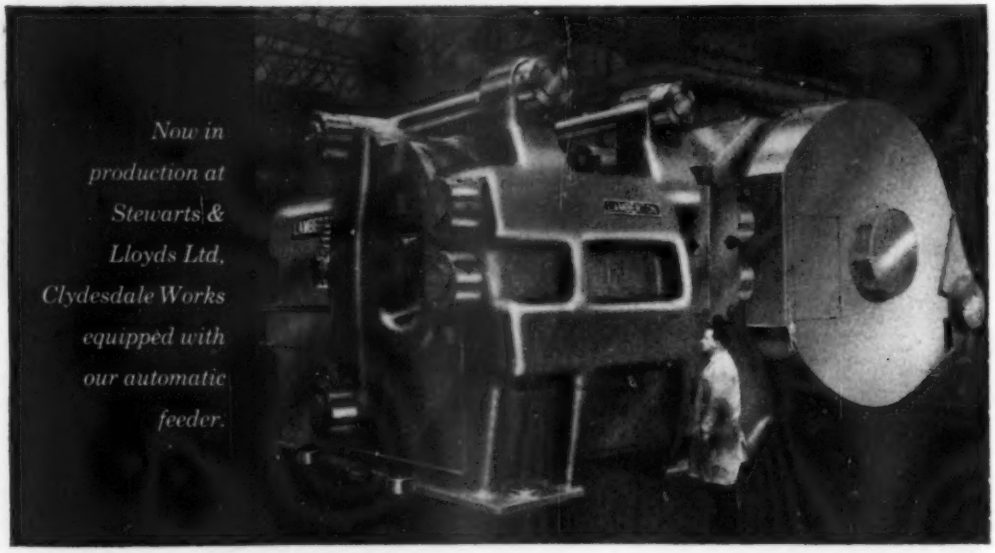
Hardened steel work rolls by Firth Brown manipulate a very high proportion of all the metals rolled in Britain. Only greatly advanced metallurgical experience and superb technical skills in their making, could achieve their preferment and "choice by the experts".

ALLOY STEELMAKERS · STEEL FOUNDERS · HEAVY ENGINEERS

THOS. FIRTH & JOHN BROWN LIMITED . SHEFFIELD · ENGLAND

LAMBERTON

10 INCH HORIZONTAL FORGING MACHINE



Now in production at Stewarts & Lloyds Ltd, Clydesdale Works equipped with our automatic feeder.

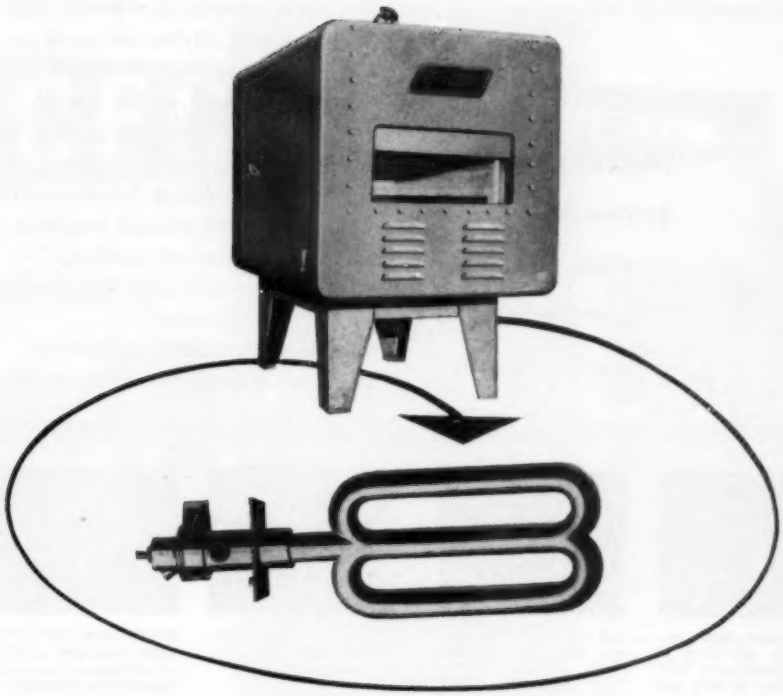
A full range of forging machines from 2 inch upwards is available – all with automatic feeding device and induction heater.

★ *Write for full details to:*

EUMUCO (ENGLAND) LTD

26 FITZROY SQUARE
LONDON W1
Telephone: EUSton 4651

Smee's E.5



Behind the success of the Radiant-Jet furnace–

lies the well-proven Jetube radiant heating element. A high recirculation rate of hot gases within the tube ensure fast and even heating of the furnace up to 1000°C. Integral recuperators give high thermal efficiency. Only Incandescent furnaces have the remarkable Jetube elements.
Send for Leaflet V.61.

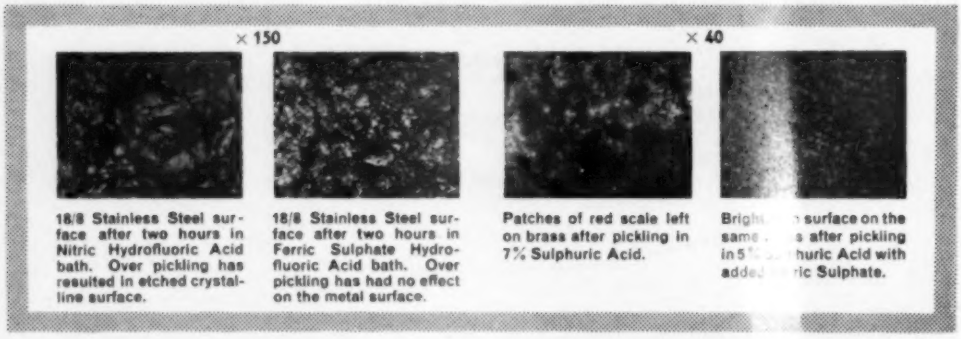
INCANDESCENT *for all heat treatment plant*

THE INCANDESCENT HEAT CO. LTD.,
SMETHWICK, ENGLAND

12/170/61

Are you concerned with annealing scale rust removal or corrosion prevention?

If you are involved in all or any of these processes then it may well be worth your while to get in touch with E. & A. West Ltd. In all probability they may be able to solve some of your problems in these fields or suggest more economical or efficient methods. Their Technical Advisory Service is at the disposal of Industry and will be glad to get to grips with your particular problem. The answer may even be in their impressive library of "case histories". Please do not hesitate to call them in. This service is freely given and non-obligatory.



18/8 Stainless Steel surface after two hours in Nitric Hydrofluoric Acid bath. Over pickling has resulted in etched crystalline surface.

18/8 Stainless Steel surface after two hours in Ferric Sulphate Hydrofluoric Acid bath. Over pickling has had no effect on the metal surface.

Patches of red scale left on brass after pickling in 7% Sulphuric Acid.

Bright surface on the same ... s after pickling in 5% ... huric Acid with added ... ric Sulphate.

Ferric Sulphate. As a pick... g agent results in rapid, clean and fume-fre... method of descaling stainless steel, co...er, brass and nickel silver and an improved method of etching mild steel surfaces prior to coating. Non-fuming, non-toxic, safely handled.
Westolite Rust Remover. This is supplied in two forms: liquid and thixotropic. The former is recommended for dipping batches of ferrous metal goods. It is a particularly efficient phosphating material which combines effectively with the surface metal to produce a protective non-rusting layer. Thixotropic Westolite has been developed for use on industrial plant, structural steelwork, and in situations where immersion is precluded. In the form of a gel, Thixotropic Westolite becomes temporarily free-flowing when applied with a brush but after application resumes its paste-like consistency. Advantages include, adherence to vertical surfaces, no drips and no wastage. Also manufactured is a range of Industrial chemicals including Dipping Acid, Nitric Acid and Hydrofluoric Acid.

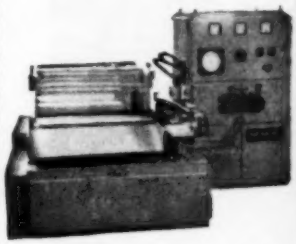
For technical advice or product data you are invited to write to:-

E. & A. WEST Limited,
Parcel Terrace,
DERBY.
Telephone: Derby 45008.

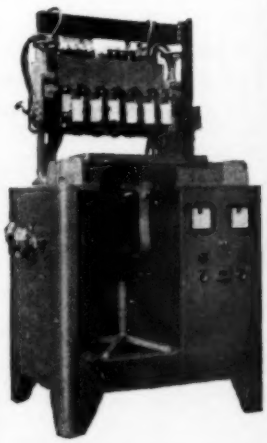
WEST
CHEMICALS FOR INDUSTRY

ACEC FORGES AHEAD . .

160 kw 8 k/c "Transaxe" type heater for heating the ends of pins.



160 kw 8 k/c Screw spike heater



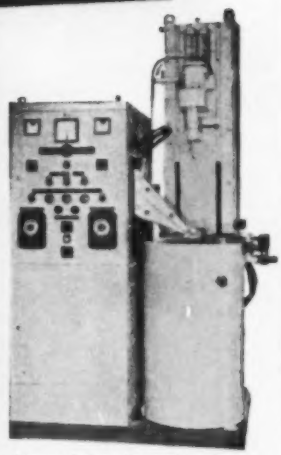
Induction Heating applied to large scale production in modern forges has many advantages over traditional heating methods, and is being widely adopted by those with an eye to the future.

From the production angle INDUCTION HEATING reduces the heating time, the formation of scale, fire losses and rejects. Regular production rates can be maintained, giving increased tool life and automatic feeding is made possible.

Labour costs are greatly reduced because kindling and cleaning operations are rendered unnecessary. Fuel handling is eliminated, automation becomes a practical possibility and hygienic working conditions a reality.

ACEC INDUCTION HEATERS are compact and can be installed exactly where needed. Accurate temperature control puts the final touch to the guarantee of a high quality product.

ACEC CHARLEROI



Above : Automatic machine for surface hardening of small cylindrical parts

Below : 100 kw 4 k/c heater for tubes

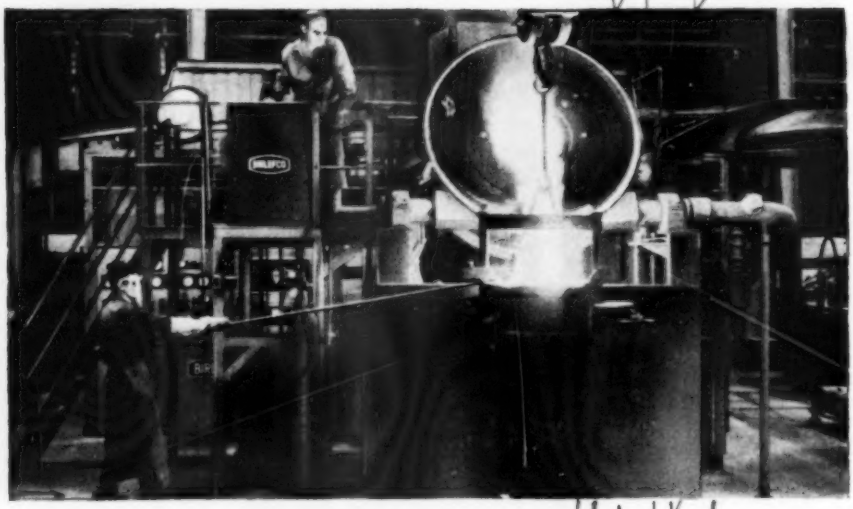
For heating of billets, pins, tubes and bars of all shapes and sizes, please get in touch with

ACEC (Ateliers de Constructions Electriques de Charleroi)
Cromwell House, Fulwood Place, London, W.C.1

Telephone : CHAncery 2932/3

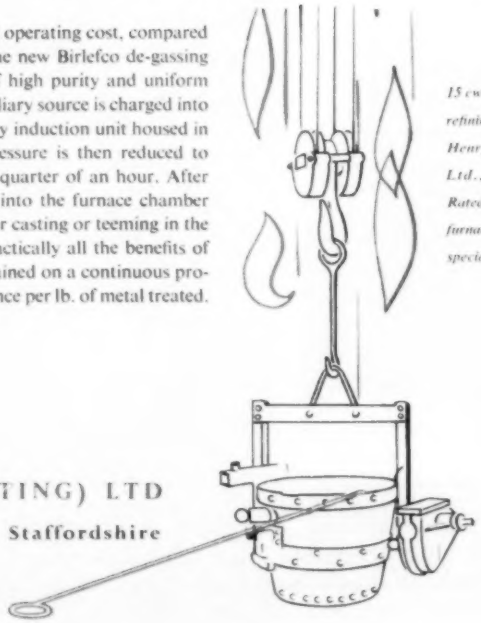
Telex : London 28678

VACUUM REFINING of MOLTEN METAL



Birlefco advance in vacuum technology

At a considerably reduced capital and operating cost, compared with conventional vacuum melting, the new Birlefco de-gassing and refining furnace ensures metal of high purity and uniform properties. Molten metal from an auxiliary source is charged into the furnace, which is a mains frequency induction unit housed in a tiltable vacuum tank. Chamber pressure is then reduced to about 250 microns and less within a quarter of an hour. After vacuum treatment air is re-admitted into the furnace chamber and the metal is poured into a ladle for casting or teeming in the conventional manner. In this way practically all the benefits of induction vacuum melting can be obtained on a continuous production basis at a cost of only a few pence per lb. of metal treated.



15 cwt. Birlefco vacuum refining unit installed at Henry Wiggin & Co. Ltd., Birmingham. Rated at 300 kW., the furnace is engaged on special alloy production.

BIRLEFCO

BIRLEC-EFCO (MELTING) LTD

Westgate · ALDRIDGE · Staffordshire

Telephone: Aldridge 52071

SMIBE 6006

May, 1961

Vol. 28, No. 188

Metal treatment

and Drop Forging

Editor DONALD GRIMMER
Production Manager R. J. LOVELL
Publisher H. J. DWYER
Area Managers
(*Southern*) D. C. RYALL
(*Midlands*) E. J. SWEETING
(*Northern*) A. D. H. CURRIE
(*Scottish*) T. H. SMITH

Official organ of the
NATIONAL ASSOCIATION OF DROP FORGERS AND STAMPERS
President S. JOHNSON
Director A. L. STUART TODD, C.B.E., J.P.
Grove Hill House, 245 Grove Lane
Handsworth, Birmingham 20
Telephone NORthern 3311-3

Published on the 15th of each month by
INDUSTRIAL NEWSPAPERS (FUEL AND METALLURGICAL) LIMITED
John Adam House
17-19 John Adam Street
Adelphi, London, W.C.2
Telephone TRAfalgar 6171 (10 lines)
Telegrams Zacatecas, Rand, London

Subscription Terms Home and Overseas 30*s.* per annum prepayable
Single copies 2*s.* 6*d.* (3*s.* post free)

CONTENTS

This journal is devoted to metals—ferrous and non-ferrous—their manufacture, properties, heat treatment, manipulation, testing and protection, with research work and development in all these fields

173 **Metallurgical qualifications**

174 **Russian forging journal**

175 **Low-temperature ageing of iron and low-carbon steel** IVAN HRIVŇÁK

A study of the low-temperature ageing of pure iron and low-carbon steel has shown the mechanism of precipitation of the nitrides. New data on the precipitation of oxides of iron was also obtained. In particular, precipitation of the oxides led to definite experimental confirmation of the dislocation model of the high-angle grain boundaries, as a synthesis of parallel Burgers boundaries

181 **Letters—metallurgical qualifications**

182 **Heat-treating springs by shaker-hearth**

183 **Some structural and physical aspects of the heat treatment of steels** K. W. ANDREWS, D.SC., D.PHIL., F.INST.P., F.I.M.

The structure at high temperatures (A_1 and above) depends in the first place on the allotropy of iron and the effects of alloy elements on this basic phenomenon. Possibilities of calculating equilibrium structures are indicated. The structural changes which occur below the A_3 or A_1 temperatures are considered in terms of the time-temperature-transformation (T.T.T.) diagram. The relation of such diagrams to heat treatment processes and to hardenability is indicated. Other aspects involved are the calculation of Ms temperatures in terms of alloy content and the relation of structure to properties

193 **Performance of forging presses** H. STERN, B.SC.(ENG.), A.M.I.MECH.E., AND CMDR. J. I. T. GREEN, O.B.E., M.I.MECH.E., M.I.MAR.E., R.N. (RET.)

Trial results on presses with direct, steam-intensifier, and accumulator drive are discussed and direct and accumulator drives are compared, the steam-intensifier being considered obsolescent

199 **Drop Forging Research Association**

200 **Automatic solvent degreasing plant**

201 **Gear and pinion forging** W. W. COLLIER

204 **Metallurgy in nuclear power technology** 8. Coolant and containment problems in reactors J. C. WRIGHT, B.SC., PH.D., A.I.M.

The metallurgy of nuclear power materials is developing on such a wide front and so rapidly that it is difficult for the non-specialist metallurgist to keep abreast with its scope. Dr. Wright outlines the subject in a series of articles

212 **News** 214 **People**

Minimum carburising time, fastest production rates and *full quality control*—these are the advantages of the Wild-Barfield Generated Gas and 'Carbodrip' methods. The benefit of many years' research is at your disposal when you write to us for advice on how gas carburising can give you a better product more efficiently.

WILD BARFIELD

WILD-BARFIELD ELECTRIC FURNACES LIMITED

ELECFURN WORKS · OTTERSPOOL WAY · WATFORD BY-PASS · WATFORD · HERTS · TELEPHONE: WATFORD 26091 (8 LINES)

W.B. 101

Metallurgical qualifications

IN principle, the affairs of a professional institution are the direct concern only of its members. Nevertheless, an effective institution will have points of interaction with the worlds of commerce and industry, and these may well prove of vital interest to the particular industry concerned. Everyone knows, today, that one of the most important of such meeting points is that of educational policy. A very high proportion of technologists in this country are taught in technical institutes, and the examination requirements of the qualifying institution will naturally be a big factor in determining the pattern of the curriculum. Changes in examination policy will, therefore, be reflected in the training, and consequently in the effective knowledge of many young technologists entering industry by way of the technical institutes.

The importance of all this is so obvious that rivers of ink have flowed through many technical fields in efforts to determine the educational policy for a young technologist preparing for the problems of his particular industry. Perhaps it was with this prodigious expenditure of ink in mind that the Institution of Metallurgists quietly determined the recent changes in its examination requirements in so unostentatious a manner. The relevant points in question are given in the letter which we print on page 181 of this issue.

It is not our intention in this column to make ourselves ridiculous by giving our particular views on education. Most amateur authorities on the subject inadvertently tell us a great deal about their own educational background, seen in an enhanced retrospect of 30 or 40 years, which is then pictured in glowing colours as a universal panacea. There is little doubt that far too many opinions on these vital questions are quite unsupported by facts and serve only to further confuse the problem. Nevertheless, the issues concerned are so far-reaching in their effects that little justification can be seen for a professional body to determine changes in educational policy without first seeking the fullest co-operation of its members, many of whom may have valuable contributions to make. Moreover, as it is in industry that most young metallurgists will seek employment, the views of as many experienced industrial metallurgists as possible should be sought.

The real problem confronting those responsible for the drafting of a suitable training scheme is the lack of factual information on the use made of the results of the training. In the chemical engineering field an attempt has been made to supply this deficiency in a recent survey by Prof. R. E. Johnstone. Prof. Johnstone undertook to find out in what way and to what extent the subjects taught at universities actually were being used by chemical engineers employed in British industry. With the aid of Mr. C. B. Lax, of the U.K.A.E.A., a questionnaire was so designed that replies would be ' factual, quantitative, and amenable to statistical analysis.' The questionnaires were sent to all corporate and graduate members of the Institution resident in the U.K., except full-time teachers. From a list of twenty-four sciences and techniques, engineers were requested to indicate which of these they had applied during the previous working week. To supplement information gained from almost two thousand engineers, Prof. Johnstone analysed his personal diary, a record of work done in industry over a period of 28 years. Results from these two sources have been used to design a suitable scheme of study for the engineer.

We hope to see, one day, a similar survey made for the metallurgical industry. Only by such a feed-back of information can a programme be satisfactorily planned to meet current needs. Meanwhile we invite readers to express their views on this subject in this journal.

Minimum carburising time, fastest production rates and *full quality control*—these are the advantages of the Wild-Barfield Generated Gas and 'Carbodrip' methods. The benefit of many years' research is at your disposal when you write to us for advice on how gas carburising can give you a better product more efficiently.

WILD BARFIELD

WILD-BARFIELD ELECTRIC FURNACES LIMITED

ELECFURN WORKS · OTTERSPOOL WAY · WATFORD BY-PASS · WATFORD · HERTS · TELEPHONE: WATFORD 26091 (8 LINES)

W.B. 101

Metallurgical qualifications

IN principle, the affairs of a professional institution are the direct concern only of its members. Nevertheless, an effective institution will have points of interaction with the worlds of commerce and industry, and these may well prove of vital interest to the particular industry concerned. Everyone knows, today, that one of the most important of such meeting points is that of educational policy. A very high proportion of technologists in this country are taught in technical institutes, and the examination requirements of the qualifying institution will naturally be a big factor in determining the pattern of the curriculum. Changes in examination policy will, therefore, be reflected in the training, and consequently in the effective knowledge of many young technologists entering industry by way of the technical institutes.

The importance of all this is so obvious that rivers of ink have flowed through many technical fields in efforts to determine the educational policy for a young technologist preparing for the problems of his particular industry. Perhaps it was with this prodigious expenditure of ink in mind that the Institution of Metallurgists quietly determined the recent changes in its examination requirements in so unostentatious a manner. The relevant points in question are given in the letter which we print on page 181 of this issue.

It is not our intention in this column to make ourselves ridiculous by giving our particular views on education. Most amateur authorities on the subject inadvertently tell us a great deal about their own educational background, seen in an enhanced retrospect of 30 or 40 years, which is then pictured in glowing colours as a universal panacea. There is little doubt that far too many opinions on these vital questions are quite unsupported by facts and serve only to further confuse the problem. Nevertheless, the issues concerned are so far-reaching in their effects that little justification can be seen for a professional body to determine changes in educational policy without first seeking the fullest co-operation of its members, many of whom may have valuable contributions to make. Moreover, as it is in industry that most young metallurgists will seek employment, the views of as many experienced industrial metallurgists as possible should be sought.

The real problem confronting those responsible for the drafting of a suitable training scheme is the lack of factual information on the use made of the results of the training. In the chemical engineering field an attempt has been made to supply this deficiency in a recent survey by Prof. R. E. Johnstone. Prof. Johnstone undertook to find out in what way and to what extent the subjects taught at universities actually were being used by chemical engineers employed in British industry. With the aid of Mr. C. B. Lax, of the U.K.A.E.A., a questionnaire was so designed that replies would be ' factual, quantitative, and amenable to statistical analysis.' The questionnaires were sent to all corporate and graduate members of the Institution resident in the U.K., except full-time teachers. From a list of twenty-four sciences and techniques, engineers were requested to indicate which of these they had applied during the previous working week. To supplement information gained from almost two thousand engineers, Prof. Johnstone analysed his personal diary, a record of work done in industry over a period of 28 years. Results from these two sources have been used to design a suitable scheme of study for the engineer.

We hope to see, one day, a similar survey made for the metallurgical industry. Only by such a feed-back of information can a programme be satisfactorily planned to meet current needs. Meanwhile we invite readers to express their views on this subject in this journal.

Russian forging journal

Abstracts from the Russian forging journal—'Kuznechno-Shtampovochnoe Proizvodstvo,' October, 1960, 2. This is the second year of this journal devoted specifically to forging. Short abstracts of the more important articles are given in METAL TREATMENT *each month.*

Deformations and strains during the drawing of components of complicated shape. YU. P. KAZAKOV. Pp. 1–4.

Based on experimental data from the drawing of automobile body components, it is shown that two forms of the state of plane strain occur, namely bi-axial extension and combined tension and compression. The initial bi-axial strain is a favourable influence. As a result of slip between the tool and the work-piece frictional forces occur, preventing further development of the biaxial strain. The final change in shape takes place mainly as a result of plastic deformation of metal not in contact with the tool. In the corners of the component strains of various signs occur, except in sections where there is very gradual transition.

Determination of the coefficient of friction during the mechanical working of metals on the basis of the theory of slip lines. P. A. IVANOV. Pp. 4–6.

Losses through contact friction may amount to 90% of the work done in deformation. A new method of determination of μ is outlined, based on determination of the extent of the zone of plastic equilibrium during the compression of a plastic medium by a semi-cylindrical or spherical tool under conditions of plane strain. In the absence of friction there will be slip along the whole contact surface between the metal and the tool, and there is no zone of plastic equilibrium. This zone, however, is proportional to μ in the presence of friction. Methods of practical determination of the zone of plastic equilibrium (zone devoid of slip lines) and calculation of μ are outlined.

A combined method of working and heat treatment of turbine disc forgings. S. A. SKORODUMOV. Pp. 6–9.

Such forgings are normally allowed to cool in air after forging and then heat treated. To avoid this waste of heat, experiments were made to utilize it for treatment. Satisfactory microstructural and mechanical properties were obtained.

Multi-position hot stamping. S. I. KLYUCHNIKOV. Pp. 10–14.

A review of the operation of such presses.

Designing tools for the shaping and flanging presses of a wheel rolling plant. M. YU. SHIFRIN. Pp. 15–19.

The design and calculation of the tools are described in full, namely the dies, shaping ring and mandrel piercer of the shaping press, and the dies of the flanging press.

The effect of die surface cleanliness on its operation. N. A. KRAVCHENKO. Pp. 20–21.

Experiments show that μ varied from 0·094–0·027 and press force for deep-drawing tests from 605–225 kg. in relation to surface cleanliness (3·25–3·5 microns down to 0·3–0·25 microns). Cleanliness was measured by the size of microscopic pits in the surface after machining.

Calculation of the passes and the tools for manufacturing bolts on automatic lines. A. N. GLADKIKH and N. I. MASLENNIKOV. Pp. 21–24.

Particular consideration is given to the production of hexagon bolts, in which the bolt head is not cut into a hexagon, but worked on an upsetting press.

Problems of designing the drive of the external ram of double-action, single-crank drive presses. N. P. KATKOV. Pp. 25–27.

The use of retinax in the clutches and brakes of presses. N. I. FIL'KIN and M. M. ROZENBLAT. Pp. 28–30.

A semi-automatic signalling system of the dimensions of heavy forgings during forging on hydraulic forging presses. O. D. BYCHKOV. Pp. 30–35.

The electro-mechanical signalling system, which is fully described, affords these advantages: semi-automatic measurement of the height or diameter of forgings with automatic signalling of maximum and minimum dimensions of the forging; prevention of excessive working on instantaneous contact with button of upper limit switch; use on various presses with rapid transferability; and automatic forging on new presses in combination with a modern control system and semi-automatic operation on old presses. It is particularly effective when forging long shafts, square bars, etc.

Local heating of billets for stamping with calculation of the required heating graphs. P. G. SHISHLAKOV. Pp. 35–37.

It is shown how local heating may be applied with

continued on page 182

Low-temperature ageing of iron and low-carbon steel

IVAN HRIVŇÁK

A study of the low-temperature ageing of pure iron and low-carbon steel has shown the mechanism of precipitation of the nitrides. New data on the precipitation of oxides of iron was also obtained. In particular, precipitation of the oxides led to definite experimental confirmation of the dislocation model of the high-angle grain boundaries, as a synthesis of parallel Burgers boundaries. By a further study of these boundaries on thin foils of aluminium it has not yet, however, been possible to prove this model experimentally*

THE STUDY OF LOW-TEMPERATURE heat treatment has great importance for an understanding of the processes which are connected with the ageing of a material, and also for the investigation of the weldability of this class of steel. During low-temperature heat treatment in the range of temperatures from 0 to 400°C. we are considering carbide and nitride precipitates. The reason for this is that both the elements, carbon and nitrogen, have increased solubility in α-iron at temperatures below the Ac_1 point. According to the literature[2, 3] the solubility of carbon is at a maximum at 723°C. and amounts to 0·025% by weight, whereas at 0°C. it falls to 0·006% by weight. More accurate data were published by Wert,[4] who established a solubility of carbon at 20°C. of the order 10^{-7}% from the results of internal friction measurements. Therefore, by rapid cooling from the temperature of maximum solubility to normal temperatures (20°C.) it is possible to obtain a supersaturated solid solution. Tsou, Nutting and Menter,[5] Doremus,[6] Pitsch[7] and others[2, 3, 4] have concerned themselves with the precipitation of carbides from a supersaturated solid solution of carbon in α-iron. Tsou, Nutting and Menter[5] established that at temperatures up to 300°C. first of all there is precipitation of the hexagonal carbide, ε-Fe_3C, which during longer periods of heat treatment in the range of temperatures up to 300°C., or at higher temperatures above 300°C., transforms into orthorhombic cementite, Fe_3C.

Jack[8] observed the breakdown of martensite in the range of low temperatures, and established that it takes place through the formation of the hexagonal carbide, ε-Fe_3C. Independently of Jack, Arbuzov[9] established by a study of the breakdown of martensite, that in the low temperature zone there is formation of the carbide Fe_xC, while at higher temperatures the transition of the carbide Fe_xC into the carbide Fe_3C is not accompanied by a change in its crystal lattice. Arbuzov explains that the cause of the great difference in the diffraction patterns of the Fe_xC and Fe_3C carbides is the lamellar form and small dimensions of the Fe_xC particles, especially the dimension of the c axis (about 10 Å) of the lattice parameters. He himself is of the opinion that it is impossible in this way to explain completely the presence of the further lines.

As early as the year 1923 the study of the precipitation of nitrides received attention in the works of Bean,[10] Sawyer[11] and Fry,[12] who showed that Fe–N alloys are capable of precipitation hardening. Mehl, Barrett and Jerabek[13] established that at low temperatures Fe_4N precipitates, and the basic planes of this precipitate can have 12 different orientations relative to α-iron. During recent years extensive studies have been made of the precipitation of nitrides from a supersaturated solid solution of α-iron. Jack[14] established during the heat treatment of nitrogenous martensite, that the analogy between the mechanisms of the breakdown of carbonaceous and nitrogenous martensite is not completely invariable. The breakdown of nitro-

*First publication. Translation by M. de O. Tollemache. The author is with the Welding Research Institute in Bratislava, Czechoslovakia. Article will be concluded in next month's METAL TREATMENT.

genous martensite does not give rise to ε–Fe_3N, but to tetragonal α″–$Fe_{16}N_2$, which slowly transforms into γ′–Fe_4N.

Another opinion was held by Dijkstra,[15] who heat treated pure iron containing about 0·05% N. At a temperature of 250° first of all he found fine precipitates, which started to coagulate after a few minutes, and after 30 minutes had a Widmanstätten orientation. After heating for 40 minutes Dijkstra was able to identify the precipitates as Fe_4N. From the morphological appearance Dijkstra judged that the first particles to precipitate were formed by the hexagonal ε–Fe_3N. Jack,[14] however, considers the conjectures of Dijkstra as improbable, since in the Fe–N phase diagram ε–Fe_3N exists only at high concentrations of nitrogen, and interprets the first precipitates as $Fe_{16}N_2$.

In the Fe–N phase diagram the following components can exist:[14, 3]

α-nitrogenous ferrite with a maximum solubility of 0·1% N at 590°C. according to Paranjpe;[15]

α′, nitrogenous martensite, structurally similar to carbonaceous martensite;

α″–$Fe_{16}N_2$, a tetragonal, metastable nitride;

γ′–Fe_4N, a cubic, face-centred nitride;

ε–Fe_4N to Fe_2N is homogeneous over the whole extent of the range of compositions from $FeN_{0·493}$ to Fe_4N. Jack[8] established that in the composition close to Fe_3N and Fe_2N the reflections agree with the structure suggested by Hendricks and Kosting in 1930; and

ζ–Fe_2N, a nitride with an orthorhombic lattice.[15]

Booker, Norbury and Sutton[16] studied the diffusion of nitrogen into various types of steel with an increasing carbon content from 0·021 to 1% C, and over the whole range of precipitation established only α″–$Fe_{16}N_2$, coherent with the [100] planes of α–Fe, and γ′–Fe_4N, without clearly marked orientations. These results and the results of his own works[17, 8, 14, 18] led Jack to work out a certain analogy between the breakdown of carbonaceous and nitrogenous martensite. During the breakdown of carbonaceous and nitrogenous martensite, α″–$Fe_{16}N_2$ iron nitride corresponds to ε-carbide of iron, and γ′–Fe_4N to cementite.

Of the remaining interstitial elements which could precipitate in α-iron, oxygen also should be considered. The solubility of oxygen in iron has not yet been definitely established. Seybold[19] gives the solubility at 900°C. as approx. 0·03 wt.% O. With decrease of temperature the solubility decreases to approx. 0·008 wt.%. An equilibrium Fe–O phase diagram was published by Darken and Gurry.[20] In this the following components exist:

FeO, wüstite, which is stable above about 565°C., and has a face-centred, cubic lattice;

FeO with a rhombohedral lattice, which is antiferromagnetic, and is formed by cooling the cubic FeO below 198°K.[21, 22];

Fe_3O_4 has a face-centred cubic lattice with a = 8·3940 ± 5 Å;

Fe_3O_4 with an orthorhombic lattice: Toombs and Rooksby[21] found that at low temperatures (119°K.) cubic Fe_3O_4 transforms into orthorhombic Fe_3O_4;

α–Fe_2O_3, hematite, which has a rhombohedral structure at normal temperatures (a = 5·42 kX, α = 55° 14′), and undergoes an anti-ferromagnetic transformation at 675°C.;

γ–Fe_2O_3 which has a cubic structure with a = 8·322 kX; and

θ–Fe_2O_3 (?) a possible, further modification of Fe_2O_3 with a hexagonal lattice.

No morphological studies of the formation and distribution of oxides of iron have yet been published.

A very good review, and an original explanation, of the influence of iron oxides on the mechanical properties of a material have recently been given by Čabelka,[23] who explained the embrittlement of steel which has been affected by heat during welding by the change in the specific volumes of the relevant iron oxides.

The aim of the present work was to provide support for the opinion of the mechanism of multi-step, ferrite grain boundaries, which has recently been published by the author,[1] and to obtain further data concerning the precipitation of nitrides and oxides in the Fe–N–O system.

General remarks

Material. The low-temperature ageing was carried out on two types of material. For exact tests we chose spectrographically pure iron, produced by the English firm of Johnson, Matthey and Co., which has an exceptionally low carbon content (table 1) and which has a sufficiently high content of nitrogen (0·012% by weight) and oxygen (0·015% by weight). This material was therefore

TABLE 1 *Chemical composition of the materials studied*

	C	Mn	Si	S	P	N	O	H	Cu
1. Johnson, Matthey spectrographically pure iron ..	0·004	$4 \cdot 10^{-6}$	0	$8 \cdot 10^{-6}$	0	0·012	0·015	0·0007	$1 \cdot 10^{-6}$
2. Steel ČSN 11370·3 ..	0·115	0·42	traces	0·03	0·014	0·008	0·010	0·005	0·11

very suitable for an investigation of the precipitation of nitrides and oxides.

In order to be able to verify the results obtained from a material with a very exact analysis on commercial steel, simultaneous experiments were carried out on the low-temperature ageing of low-carbon steel to specification ČSN 11370·3 (table 1).

Method. For the study of low-temperature ageing use was made on the one hand of observation with an optical microscope, and on the other hand by means of electron microscopy and electron beam diffraction. Measurements were also made of the microhardness of the ferrite.

For observation with the optical microscope the ordinary metallographic method was employed, and the specimens were electrolytically polished in a solution of the type $CH_3COOH + HC10_4 + H_2O$ at normal current densities. In all instances, whether it concerned the precipitation of nitrides or of oxides, the specimens were etched with a 3·5% solution of HNO_3 in alcohol.

For observation with the electron microscope, mainly carbon extraction replicas were used, but in certain instances, mainly for the study of the precipitation of oxides, collodion extraction replicas were used. These replicas were likewise employed for transmission electron diffraction.

As instruments, for the most part use was made of a prototype, Tesla BS-242, table-type, electron microscope, while selective diffraction within the range $< 3\mu$, and also the study of thin foils, were carried out on an experimental, Czechoslovak electron microscope with a high power of resolution. Back reflection diffraction was carried out on a Trüb and Teuber instrument.

Micro-hardness measurements were made by the Hanemann system with a loading of 50 g.

Experimental section

Heat treatment

Before the low-temperature ageing both the materials, the Johnson, Matthey iron and the ČSN 113703, low-carbon steel, were homogenized for 4 h. at 950°C. and then cooled in air to 700°C., from which temperature they were quenched in water. For the low-temperature ageing 4 isotherms were chosen: 100, 200, 300 and 400°C. For each isotherm 5 heating periods were chosen: 10 min., 1, 10, 50 and 100 h. Some of the specimens were also aged at room temperature, *i.e.*, at about 25°C., for a period of one month.

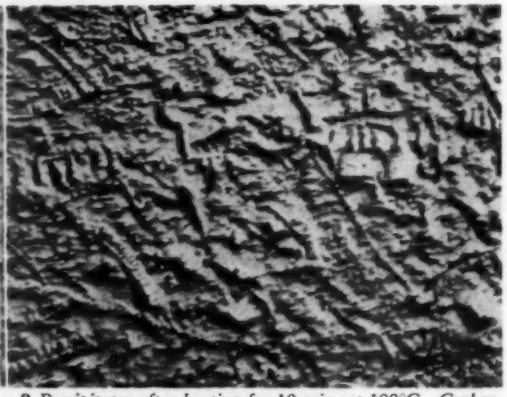
Low-temperature ageing of pure, Johnson, Matthey iron

1. *Ageing at 25°C.* After a period of ageing of one month spontaneous precipitation was observed. Shorter periods of ageing were not investigated. In general it is possible to distinguish two morphological types of particles, namely fine needles or rods, whose length attains 2,000–3,000 Å, while their thickness does not exceed about 500 Å. These needles can build different formations, but for the most part precipitate in the form of discrete lines, such as may be seen in fig. 1 at the points indicated by the short arrows. Around these formations, which have probably precipitated at the dislocations, the acicular particles can also form other, for the most part indefinable structures, some of which are also visible in fig. 1.

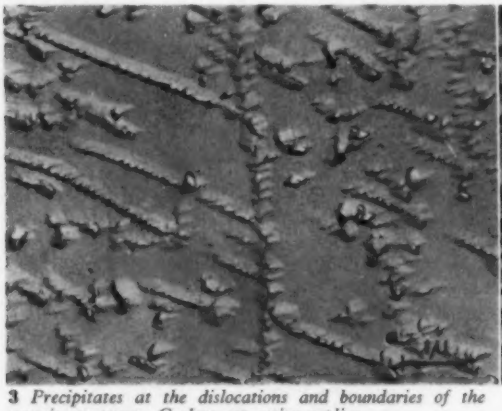
Yet another form of the precipitates is visible in fig. 1; these are the fine, coagulated particles with a dimension of about 500 Å, which for the most part have a tendency to precipitate in definite atomic planes. And though this tendency will be markedly revealed in other specimens, even in fig. 1 its direction is indicated by the long arrow, and by etching on the [100] plane in conformity with Barrett[24] in a solution of 1 part HNO_3 and 4 parts H_2O, it was possible to establish that the planes mentioned, in which the fine precipitates are liberated, are the [100] planes of the α-iron. By electron diffraction using the back reflection method, the coarser, acicular particles were identified as ε–Fe_3N. The fine, coagulated particles were masked during diffraction by the coarser, acicular nitrides, but, as we shall see later, these particles correspond to the oxide of iron, α–Fe_2O_3.

2. *Ageing at 100°C.* The initial states of precipitation are similar to that at 25°C. Even after heating for 10 min. it is possible to find marked, plate-like and acicular precipitates, which are liberated in characteristic, discrete lines, which coincide with the boundaries of the mosaic structure (veining) or with other lattice defects (fig. 2). Around these plate-like formations, in the structure fine particles are also included, which belong to the oxide α–Fe_2O_3. The precipitates in fig. 2 are very difficult to pick out. Observations were therefore also made of the grains of the polycrystalline material, in which the precipitation of the oxide particles is clearly marked. The possibility of observing these particles is also very much dependent on the relative orientation of the grain with reference to the plane of the polished surface.[25] In fig. 3 is recorded likewise an area in which are visible only marked, plate-like particles of ε–Fe_3N, precipitated on the one hand on the boundary of the mosaic structure, and on the other hand discrete lines at the dislocations. After heating for one hour growth of the nitride particles into larger platelets takes place, and after 10 hours' ageing these particles form a typical Widmannstätten orientation. This arrangement of the particles is characterized by fig. 4, in which it is in fact possible to see fine, oxide

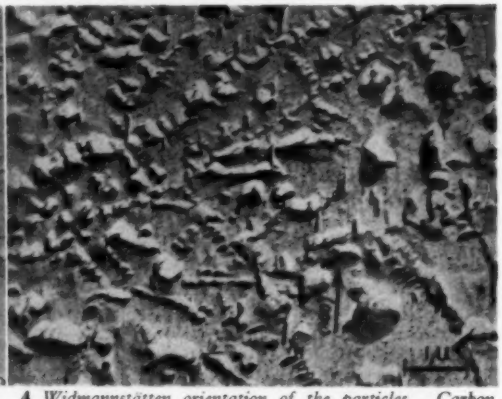
1 *Particles of* ε*–*Fe_3N *and* α*–*Fe_2O_3 *precipitated after ageing for one month at 25°C. Carbon extraction replica*



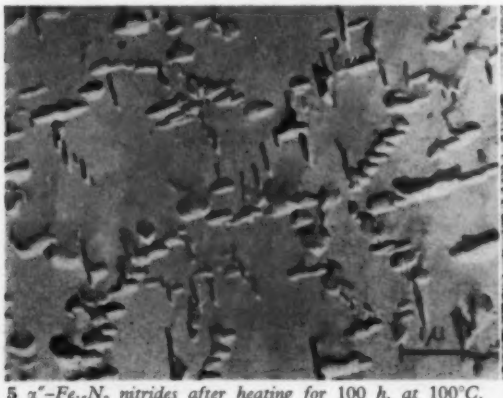
2 *Precipitates after heating for* 10 *min. at* 100°*C. Carbon extraction replica*



3 *Precipitates at the dislocations and boundaries of the mosaic structure. Carbon extraction replica*



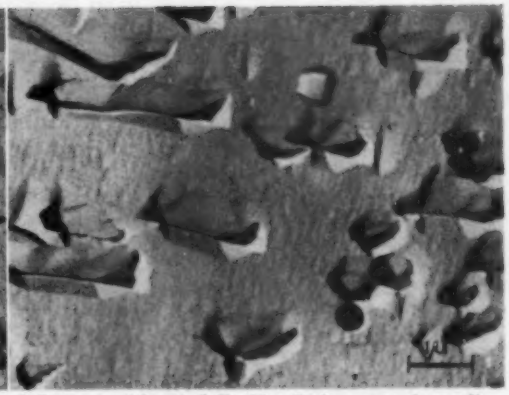
4 *Widmannstätten orientation of the particles. Carbon extraction replica*



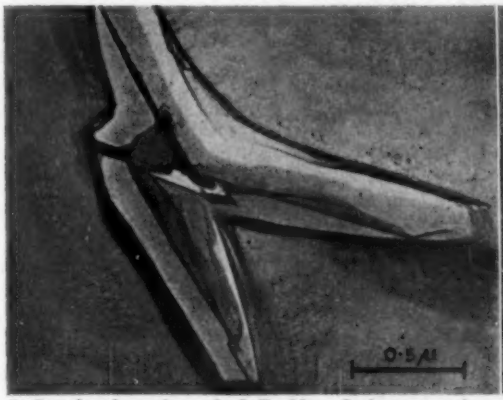
5 α''*–*$Fe_{16}N_2$ *nitrides after heating for* 100 *h. at* 100°*C. Carbon extraction replica*

6 *Precipitates of* ε*–*Fe_3N *and* α*–*Fe_2O_3 *after heating for* 10 *min. at* 200°*C. Carbon extraction replica*

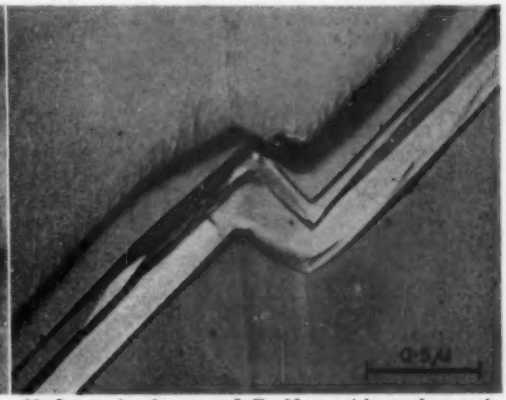
7 *Advancing precipitation after heating for one hour at 200°C. Carbon extraction replica*



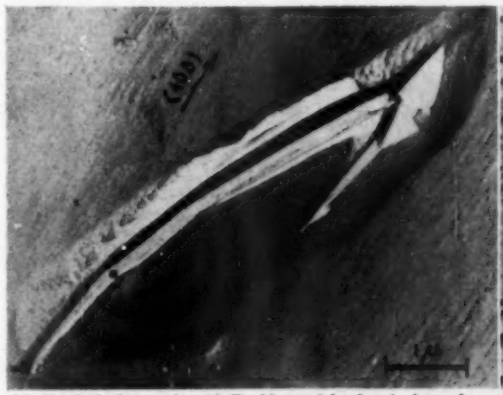
8 *Coarse particles of α''–$Fe_{16}N_2$. Carbon extraction replica*



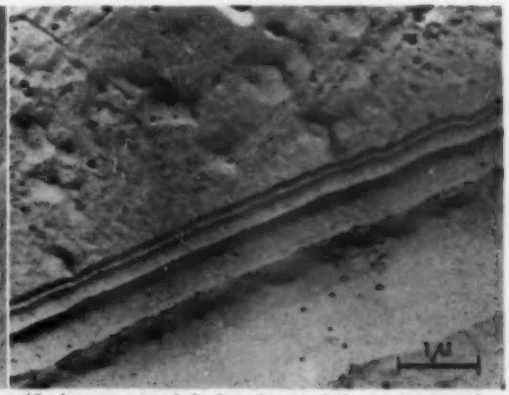
9 *Complex formations of α''–$Fe_{16}N_2$. Carbon extraction replica*



10 *Interaction between α''–$Fe_{16}N_2$ particles and a grain boundary. Carbon extraction replica*



11 *Typical shape of a γ'–Fe_4N particle, herringbone formation. Carbon extraction replica*



12 *Arrangement of the boundary and the precipitates after heating for one hour at 400°C. Carbon extraction replica*

particles, precipitated in the [100] planes of the α-iron.

On increasing the period of ageing to 50 and 100 h., in essence there is no change in the morphology of the particles (fig. 5).

3. *Ageing at* 200°C. The initial states and the growth of the precipitates may be very clearly followed at a temperature of 200°C. At this temperature the particles no longer form such impenetrable clusters, and indeed the particles of nitrides and oxides may be differentiated by their size. The initial structure, such as was recorded after heating for 10 min. at 200°C., is shown in fig. 6. The nitrides, which were identified by electron diffraction as ε-Fe_3N, precipitate for the most part in discrete lines, and have a rod-like, or moderately plate-like, morphology. In fig. 6 is marked the direction of the [100] planes of the α-iron, as it was established by etching on the [100] plane. It is evident that the first particles of ε-Fe_3N are parallel with this direction. As soon as further growth (A) takes place, the particles change their orientation, and from morphological studies it is impossible to establish any marked relationships in their orientation.

The progress of this growth tendency is readily visible after heating for one hour at 200°C. In

TABLE 2 *Reflections for ε-Fe_3N, ζ-Fe_2N and α″-$Fe_{16}N_2$ in pure iron*

No.	10 min. at 200°C.		ε-Fe_3N†	1 h. at 200°C.*		ε-Fe_3N†	ζ-Fe_2N†	10 h. at 200°C.		ζ-Fe_2N†	100 h. at 200°C.*		α″-$Fe_{16}N_2$‡
	d Å	Intensity	d Å	d Å	Intensity	d Å	d Å	d Å	Intensity	d Å	d Å	Intensity	d Å
1	2·80	m.w.	2·80	—	—	—	—	—	—	—	—	—	—
2	—	—	—	2·52	v.s. diffuse	—	2·40	—	—	—	—	—	—
3	2·38	m.w.	2·38	—	—	—	—	—	—	—	—	—	—
4	2·01	s.	2·09	2·01	v.s. oriented	2·09	—	—	—	—	2·02	oriented	2·019
5	1·54	v.w.	1·61	1·57	v.s. diffuse	—	1·62	1·60	s. diffuse	1·62	1·59	oriented	1·573
6	—	—	—	—	—	—	—	—	—	—	1·43	oriented	1·428
7	—	—	—	—	—	—	—	—	—	—	1·40	oriented	1·409
8	1·38	s.	1·37	1·45	s. oriented	1·37	—	—	—	—	1·37	oriented	1·378
9	—	—	—	—	—	—	—	—	—	—	1·29	oriented	1·300
10	—	—	—	—	—	—	—	—	—	—	1·26	oriented	1·264
11	—	—	—	1·19	s. diffuse	—	1·18	1·23	v.w. diffuse	1·18	1·23	oriented	1·241
12	1·14	v.w.	1·14	—	—	—	—	—	—	—	—	—	—
13	—	—	—	—	—	—	—	1·03	m.s. diffuse	1·05	1·05	oriented	1·057
14	—	—	—	1·00	w. diffuse	—	1·00	1·00	m.s. diffuse	1·00	0·98	oriented	—
15	—	—	—	0·91	w. oriented	0·92	—	—	—	—	—	—	—
16	0·80	v.w.	0·82	—	—	—	—	0·79	v.w. diffuse	—	—	—	—

*Collodion extraction replica.
†ASTM, according to Hendricks and Kasting, *Z. Krist.*, 1930, **74**, 512.
Hagg, *Nova Acta Reg. Sci. Ups.*, Ser. IV, **7**, (1), 21.
‡According to Jack, *Proc. Roy. Soc.*, 1951, **208**, 216.
Intensity: v.s., very strong; m.s., medium strong; s., strong; m.w., medium weak; w., weak; v.w., very weak.

fig. 7 we can see easily their overall growth and their more pronounced, plate-like shape, while at the same time the first particles, at the ends of the lines, remain parallel with the direction of the [100] planes of the α-iron.

The further growth after heating for 10, 50 and 100 h. is already analogous to that at the 100°C. isotherm. After 100 h. the particles are markedly lamellar, and have a Widmannstätten texture. Their morphology is characterized by fig. 8. The electronographical identification of the precipitates taking place during the ageing at 200°C. are given in table 2.

4. *Ageing at* 300°C. Once again precipitation starts with fine, plate-like particles, identified by electron diffraction as ε–Fe_3N, but even after heating for 10 min. it is no longer possible to identify such marked orientations as in fig. 6, for instance.

After heating for one hour a pronounced texture is already formed, similar to that in fig. 5.

After heating for 10 h. there is already incomplete transformation of the ε–Fe_3N into α″–$Fe_{16}N_2$. Around the familiar platelets, the particles of $Fe_{16}N_2$ can form other complex formations. A combination of several platelets, or lamellae, is characterized by fig. 9. Another instance, the transition of $Fe_{16}N_2$ particles through the grain boundary, is characterized in fig. 10, which was obtained after heating for 50 h. at 300°C. During these longer periods of ageing transformation of α″–$Fe_{16}N_2$ into γ′–Fe_4N also takes place. The mechanism of this transformation will be similar to that which Booker, Norbury and Sutton[16] described. Firstly dissolution of $Fe_{16}N_2$ takes place mainly in the zone around the grain boundaries, and simultaneously formation of coarse particles of γ′–Fe_4N for the most part at the grain boundaries. But the orientation of these particles does not stand in any marked relationship to the grain boundaries. The individual particles of Fe_4N form either coarse platelets, or even more typical, pronged structures, as is evident, for instance, from fig. 11, which was obtained after heating for 100 h. at 300°C.

5. *Ageing at* 400°C. At 400°C. it was possible after 10 min. and to some extent after one hour, to discover fine, coagulated particles (fig. 12), which did not subsequently change their size or character. These particles probably belong to the oxide of iron and not to its nitride, as a temperature of 400°C. is above the range of stable existence of the nitride. Fig. 12 also shows clearly enough a multi-step ferrite grain boundary, as this has been interpreted in an earlier work.[1]

to be continued

LETTERS *to the Editor*

Metallurgical qualifications

SIR: Many of your readers may be unaware that the Institution of Metallurgists is in the process of changing the nature and mechanism of its examinations policy. Since the Institution is the major qualifying body for metallurgists, especially those employed in industry, such changes should be of direct concern to all metallurgists. The new arrangements for the Licentiateship examinations have recently been published (*The Metallurgist*, January, 1960, **1**, (1), 25) and are due to come into operation in 1963, but studies for these new examinations will start in 1962. While there are bound to be many conflicting opinions on any change in examination policy, a substantial body of opinion among teachers of metallurgy and industrial metallurgists feels that the views and experience of a sufficiently representative body of metallurgists was not canvassed before the final proposals for a revision of the Associateship examinations. This would appear to be an illogical method of making public such an important professional matter, since the Licentiateship and Associateship qualifications cannot be considered independently. The lack of information on the Associateship requirements to a large extent has precluded intelligent discussion of the Licentiateship proposals. It is hoped that it is not too late to promote healthy discussion on this very important change which seems to be in danger of being presented as a ' fait accompli.'

Finally, on another matter, the profession should be very concerned that the Institution shows extreme reluctance in recognizing the parity of the Diploma in Technology with a University degree in metallurgy in relation to the existing qualification requirements for Associateship of the Institution of Metallurgists. In this respect, the Institution is taking a diametrically opposed view to that of other comparable professional bodies.

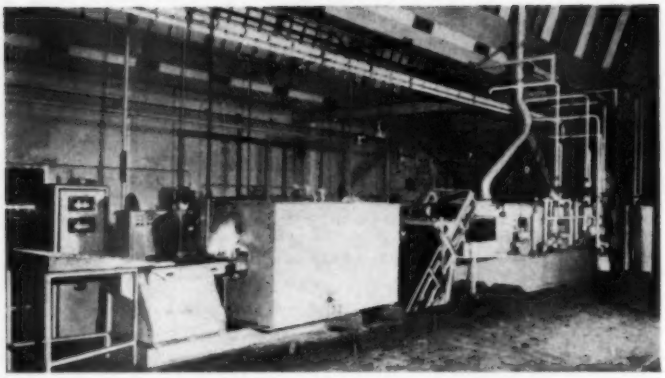
A. D. HOPKINS
College of Advanced Technology, Birmingham.
Department of Metallurgy.
April 13, 1961

United Steel to develop airstrip near Sheffield

The United Steel Companies Ltd. have purchased 108 acres of land near Coal Aston, 10 miles to the south of Sheffield, for development as an airstrip for use by the company's aircraft, and work is now proceeding on the preparation of an 800-yard long grass runway.

When completed in the early summer it will enable customers and senior executives to reach United Steel's head office in 15 minutes by car, with about half-an-hour's travelling to the company's steelmaking branches in the Sheffield area.

Heat-treating springs by shaker-hearth



Efco 50-kW. shaker-hearth furnace, quench elevator and washing machine used to harden Terry springs

TO MAINTAIN AND IMPROVE the quality of their products, Herbert Terry & Sons Ltd. have installed new heat-treatment plant in their works at Redditch. Their extensive range of springs and presswork, varying considerably in size and complexity, is now being hardened in shaker-hearth furnaces providing closed quench facilities. The new furnaces ensure consistent hardness and a superior surface finish.

In both furnaces the springs are moved through a horizontal heating chamber by an oscillating nickel-chromium hearth plate having a machined and polished surface. The hearth is operated in one direction by an electric motor and in the other by a spring return mechanism, and its oscillating frequency can be varied to give a wide range of conveyor speeds. The heated springs fall from the hearth through a quench chute which is sealed to the furnace casing and has its lower end projecting into the quenching medium. Heating elements are placed above and below the hearth, and around the quench chute to ensure quenching at the full hardening temperature. The elements are spirals of nickel-chromium wire, wound on formers and enclosed in nickel-chromium tubes. They can be removed through the side of a furnace without closing it down. The furnaces provide temperatures up to 950° C.

One of the furnaces is rated at 50 kW. and has a hearth 18-in. wide with a heated length of 5 ft. arranged in two independently controlled zones each with its own automatic temperature-indicating controller. This furnace has an oil quench tank fitted with oil cooling and circulating equipment. The tank projects behind the furnace where the quenched springs are removed by a slat-conveyor elevator which discharges them on to the conveyor belt of an automatic washing machine beyond the furnace. Here the springs are washed, rinsed and dried.

The other furnace is rated at 20 kW. and has a hearth 12-in. wide with a heated length of 2 ft. 6 in. The temperature is controlled in one zone with an automatic indicating controller. The quench tank is arranged with its effective length of 8 ft. at right-angles to the line of the furnace. The springs drop into baskets which are inserted into the tank on one side of the furnace and then moved by hand-operated propelling gear to the other side for unloading.

A controlled atmosphere is used in the furnaces to protect the springs from oxidation and decarburization. It is supplied by an endothermic generator operating on town's gas and capable of an output of up to 1,000 cu. ft./h. To maintain the surface carbon of the springs at the required level the gas : air ratio is set to give a dewpoint at the generator of 20–25° F. and this is checked regularly with an Alnor dewpoint meter.

The output of the furnaces depends upon the volume-to-weight ratio of the parts being hardened. In the most favourable circumstances the larger furnaces can give outputs up to 340 lb./h., and the smaller furnace a maximum of 126 lb./h. The average outputs are, however, 208 and 78 lb./h. respectively.

The shaker-hearth furnaces, the endothermic generator and the Alnor dewpoint meter were all supplied by Efco Furnaces Ltd. The automatic washing machine was manufactured by Electro-Chemical Engineering Co. Ltd.

Russian forging journal

concluded from page 174

advantage to billets requiring to be forged in strictly limited areas and graphs are prepared to show the heating temperature gradients in proportion to the degree of working.

Methods of reducing the prime cost of induction heating of forging billets. V. S. BYALKOVSKAYA. Pp. 38–40.

Methods of reducing power consumption are discussed.

A 12-position, universal, vertical blanking head for group working of strip components by elements. V. M. KOLOSOV. Pp. 41–43.

Automatic ejectors for removal of components during cold stamping. L. S. SAGATELYAN and L. M. TSIRIK. Pp. 44–45.

A pendulum and lever-type ejector are described.

Some structural and physical aspects of the heat treatment of steels

K. W. ANDREWS, D.Sc., D.Phil., F.Inst.P., F.I.M.

The main purpose of this article is to suggest the dependence of the useful properties of alloy steels upon various structural and physical factors. The structure at high temperatures (A_1 and above) depends in the first place on the allotropy of iron and the effects of alloy elements on this basic phenomenon. Possibilities of calculating equilibrium structures are indicated. The structural changes which occur below the A_3 or A_1 temperatures are considered in terms of the time-temperature-transformation (T.T.T.) diagram. The relation of such diagrams to heat treatment processes and to hardenability is indicated. Other aspects involved are the calculation of Ms temperatures in terms of alloy content and the relation of structure to properties*

THE HEAT TREATMENT of steel is a branch of technology which has its roots in antiquity, but with the progress of time understanding of the basic scientific principles has been greatly advanced. It is now clear, for example, that the properties of the various kinds of steel at our disposal depend on their structure—that is to say on the composition and crystallography of the phases present and the relative size, shape and distribution of particles. Among the most useful phenomena involved are the allotropy of iron itself, the form of the iron-carbon diagram and the mode of approach to equilibrium at sub-critical temperatures. Another important aspect is the influence of various alloying elements.[1]

The heat treatment of steels is therefore within the proper province of physical and structural metallurgy. The steel user now has at his disposal a very considerable variety of steels and a number of commercially practicable heat treatments. In this he is assisted by the existence of a certain amount of data in the form of diagrams—such as isothermal transformation or 'T.T.T.' diagrams. It is intended here to take a very general view of the subject. We shall, for example, want to emphasize some of the basic principles and to enquire whether, or how far, the science is on a quantitative footing since this is clearly one aim of the physical approach to any technology. For a general consideration of the whole subject the reader may refer to some of the established works[1, 2] or to a recent survey.[3]

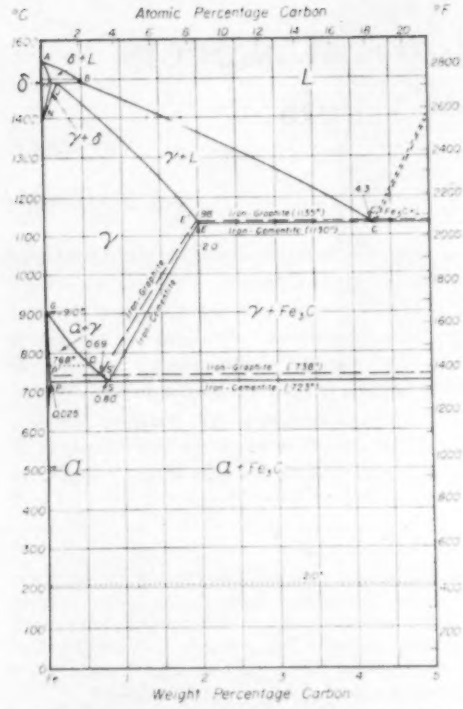
The basic facts may therefore be summarized:

1. The allotropy of iron.
2. The effect of carbon (Fe–C diagram).
3. The effect of other alloy elements considered either as influencing 2 or independently.
4. Equilibrium involving ferrite, austenite or carbide(s) in various combinations.
5. The importance of rate of approach to equilibrium, the existence of metastable states, and the effects of diffusion and diffusionless transformations.
6. The aim of heat treatment is to bring the steel into the desired structural state so it will have the desired properties.
7. It follows that we must also try to find how this dependence of properties on structure arises.

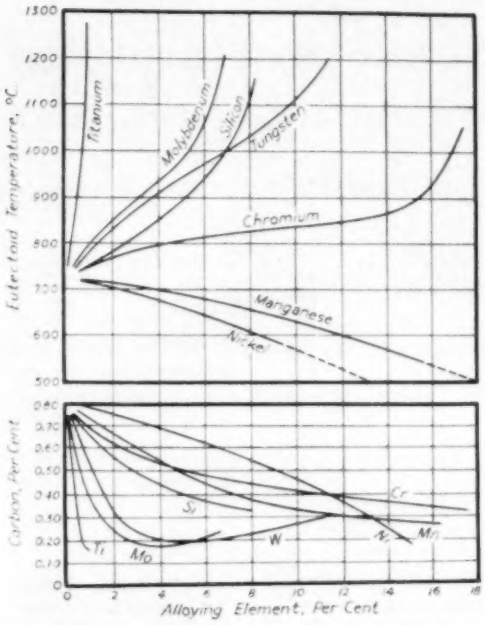
Allotropy and effects of alloy elements on equilibrium

In general a heat-treatable steel contains carbon and a number of other alloy elements. These may be considered from the point of view of their origin or from the standpoint of function.

*A communication from the Research & Development Department, United Steel Companies Ltd. (Swinden Laboratories), based by the author on his lecture given at the Birmingham College of Advanced Technology last January in the series 'Modern developments in the theory and practice of steel heat treatment.' Articles based on other lectures in the series will be published in future issues of METAL TREATMENT.



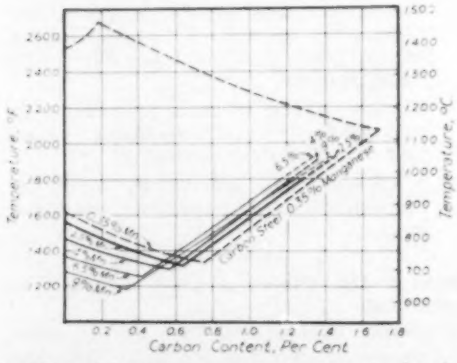
1 *Iron-carbon equilibrium diagram (by kind permission of the American Society for Metals from 'Metals Handbook')*



3 *Effects of alloy elements on eutectoid compositions and temperatures (after Bain[1])*

ORIGIN

1. Added to produce effects such as hardness, creep resistance, oxidation resistance (C, Ni, Cr, etc.).
2. Present and generally controlled (*e.g.* Si and Mn).
3. Incidentally present from various sources but generally kept as low as possible (S, P, H, O, etc.).

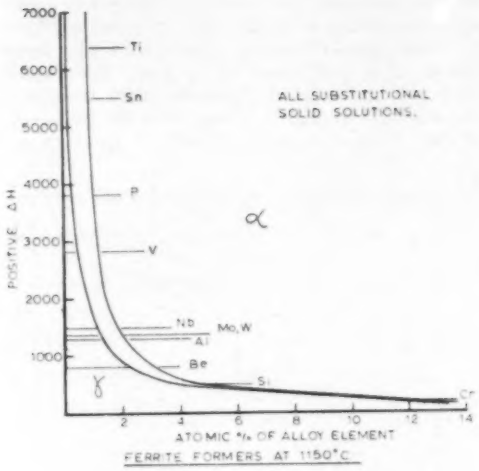


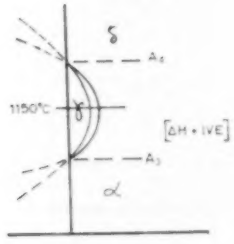
2 *Effect of increasing manganese content on the phase boundaries of austenite in equilibrium with ferrite or pearlite (after Bain[1])*

FUNCTION

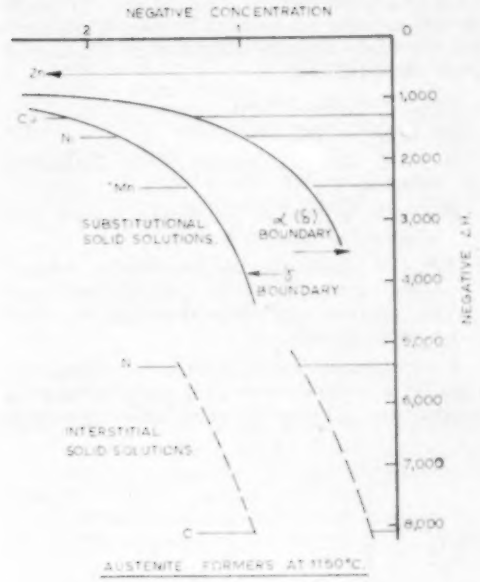
1. With respect to the allotropy of iron itself: (1) Ferrite formers; (2) austenite formers.
2. With respect to relative importance as: (1) Solid solution formers, (*a*) substitutional, (*b*) interstitial; (2) carbide (or nitride) formers; (3) deoxidizers, desulphurizers, etc. (leading to the presence of inclusions).

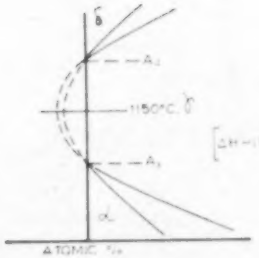
In the first instance, we are concerned with the iron-carbon diagram (fig. 1) which reveals the function of carbon itself—obviously a carbide former but also a strong austenite former. The solid solutions in austenite and the much more restricted solution in ferrite are interstitial. This also applies to nitrogen. The other common alloy elements form substitutional solid solutions, and they may be considered to affect the equilibrium represented in fig. 1 by the way in which they shift the solubility lines such as *GS* or *ES* or the eutectic. A diagram due to Wells and taken from Bain[1] is shown in fig. 2. It indicates the effect of manganese





4a *Relation between (calculated) ΔH and equilibrium at 1,150°C. illustrating relative effects*





4b *Relation between (calculated) ΔH and equilibrium at 1,150°C.*

additions. Fig. 3 illustrates the effects of most of the elements which are commonly used in alloy steels on the eutectic temperature and composition. Such empirical diagrams have considerable practical value and could well be used more extensively.

The general effect of alloy elements as represented by their equilibrium diagrams with iron can be interpreted in terms of Wever's classification.[4] The writer discussed this subject some years ago in this journal[5] and the scheme of Wever is well known. Fundamentally, however, there are really only two basic types already implicit in the use of the terms 'ferrite former' and 'austenite former.' The 'expanded γ field,' of which fig. 1 is a typical case, merely depends on the relative stability of the phase which ultimately enters into equilibrium with the austenite. It is observed that the elements which stabilize the austenite phase are the interstitial elements C and N, and elements which appear in Groups VII and VIII of the periodic table in the transition series (Mn, Ni, Ru, etc.). The elements which favour the ferrite phase are generally in Groups IV, V and VI of the same series (Ti, V, Cr, etc.) together with Al, Si and P. This relationship with the Periodic Table was also realized by Wever.[4, 5] The system Fe–Cr with the minimum in the γ loop may appear to be an anomaly and has been considered such, but this view may not be strictly correct (see below).

The two possible effects of alloying elements on the allotropy of iron are summarized in fig. 4. The elements which stabilize austenite may be regarded as forming a 'negative gamma loop.' A thermodynamic treatment by Zener,[6] Oelsen and Wever[7] and others (*e.g.*[8]) suggests that such diagrams can be represented by a single parameter ΔH which determines the concentration of the alloy elements in austenite and ferrite in equilibrium.

Thus for a ferrite former (γ loop system) ΔH could be derived from the point of maximum solubility and the whole diagram could then be constructed from the equations:

$$C^{\alpha}/C^{\gamma} = \beta \exp. \Delta H/RT \quad \ldots\ldots\ldots\ldots\ldots (1)$$

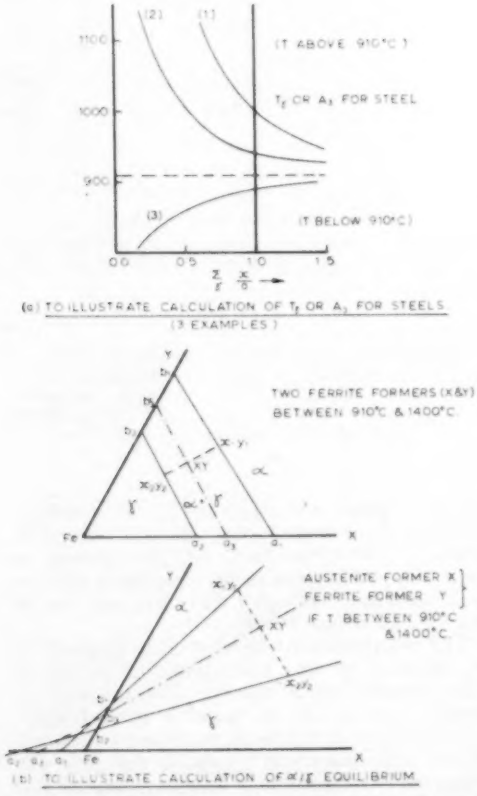
$$1-C^{\alpha}/1-C^{\gamma} = \exp. -\Delta F_{Fe}/RT \quad \ldots\ldots\ldots\ldots (2)$$

(β = 1 for substitutional, 3 for interstitial solutions).

Here ΔH is positive for ferrite formers and negative for austenite formers.

ΔF_{Fe} = Difference in free energy between α and γ iron. (The writer had previously used the opposite sign convention[5] but the above is more general).

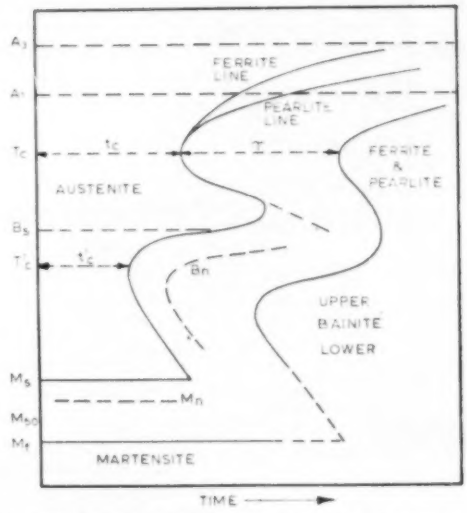
It is, however, true to say that ΔH cannot be regarded as constant over an appreciable range of temperature although in some cases agreement between calculated and observed γ loops was found to be reasonable assuming that ΔH was constant as a first approximation. Zener used two parameters in a later treatment.[9] Later Kauffmann gave a more detailed thermodynamic treatment and was able to suggest a reason for the minimum in the γ loop in the system Fe–Cr.[10] In effect the equilibrium reverses because some of the terms in the thermodynamic equations are small and vary differently with temperature. We can say that chromium is a weak ferrite former and any similar weak ferrite formers (if they existed) would tend to show a γ loop minimum.



5 *Calculations for low-alloy steels including austenite/ferrite equilibrium*

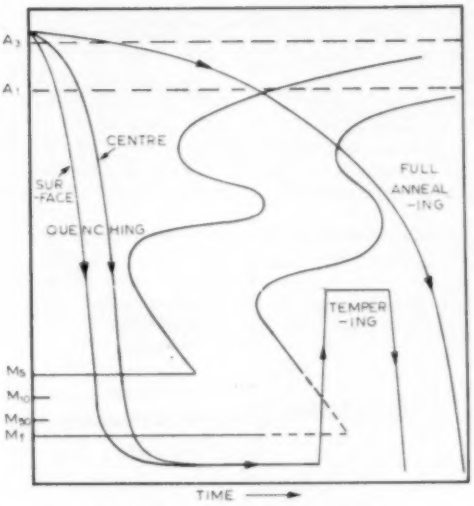
This point about the weak effect of Cr will be appreciated by reference to fig. 4 where we show ΔH values obtained from maximum solubility or from suitable points on the diagram for depressed transformations. This quantity ΔH can be regarded as a measure of the 'relative strength' of the alloy element—notwithstanding the above reservations about its variation with temperature. It would perhaps be possible to take the accurately established binary diagram as a base and use equations such as the above to measure the variation of ΔH with temperature. From a practical point of view, however, we should be more interested in ascertaining whether there is any possibility of extrapolating from the binary systems to actual steels, and this point deserves more consideration.

From this point of view it should be possible to make use of diagrams such as fig. 2 to estimate the



6 *Basic features of isothermal transformation diagram*

effects of individual alloy elements and then to combine these effects in a formula. The equations would be linear to a first approximation, and deviations from linearity could be taken account of by the use of additional terms probably involving



7a *Two traditional heat-treatment procedures seen in relation to the isothermal diagram*

products of concentrations. The writer has pointed out elsewhere[11] that if equations such as (1) above apply in ternary or higher alloy systems and equation (2) generally represents the ratio of iron concentrations in the two phases, then providing interactions between alloy elements are small or otherwise the solutions are regarded as 'dilute' then it follows that isothermal boundaries are straight lines in ternary systems, planes in quaternary systems or hyperplanes in higher order systems. The equation to a plane has the general form $(x/a) + (y/b) = 1$ and the hyperplane

$$\Sigma x/a = 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

for any number of terms. Such an equation would apply either to the α boundary or the γ boundary—in the latter case this is the A_3 point for the steel.

The equation (3) represents a phase boundary but in general a given alloy does not lie on the phase boundary. For a steel even within a given specification we have an arbitrary set of composition co-ordinates. If, however, these are inserted in expressions such as (3) for a series of temperatures the sum may not equal unity but have values on either side. If then the sum $\Sigma\gamma$ for (say) the $\alpha+\gamma/\gamma$ boundary is plotted against temperature then we can read off the temperature T_γ (or A_3) for the steel. This procedure is indicated in fig. 5*a* and in principle is *a method of calculating minimum austenitizing temperatures*.

A further development follows and is indicated in fig. 5*b*. If an alloy or steel of arbitrary composition lies in the two-phase region $\alpha + \gamma$ at a heat-treatment temperature then it can also be inferred that if its composition is *XYZ* . . . then it lies on a hyperplane

$$(X/a_3) + (Y/b_3) + (Z/c_3) = 1 \quad \ldots\ldots\ldots\ldots \quad (4)$$

where $a_3 = \varepsilon a_1 + (1 - \varepsilon)a_2$

$b_3 = \varepsilon b_1 + (1 - \varepsilon)b_2$

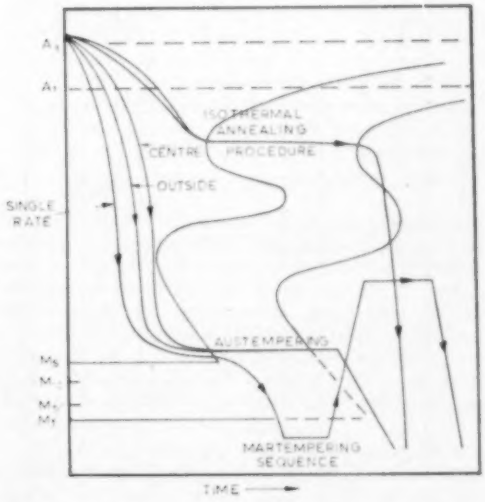
and $\varepsilon/(1-\varepsilon)$ = proportion of α/proportion of γ

The partition of alloy elements is given by

$$X = \varepsilon x_1 + (1-\varepsilon)x_2$$

Here the quantity ε can be found by a graphical method similar to that of fig. 5*a*. This procedure for calculating the constitution of phases in equilibrium could be of quite general application.

In practice the use of such methods is limited by the original assumptions and the extent to which



7b *Three special heat-treatment processes seen in relation to the isothermal diagram*

they are invalidated by interactions between alloy elements. It is considered, however, that a suitable combination of the thermodynamics with empirical relationships could enable these aspects of heat treatment to be put on a more quantitative basis.

Thus for a ferrite former (γ loop system) ΔH could be derived from the point of maximum solubility and the whole diagram could then be constructed from the equations:

$C^{\alpha}/C^{\gamma} = \beta \exp. \Delta H/RT$ ..... (1)

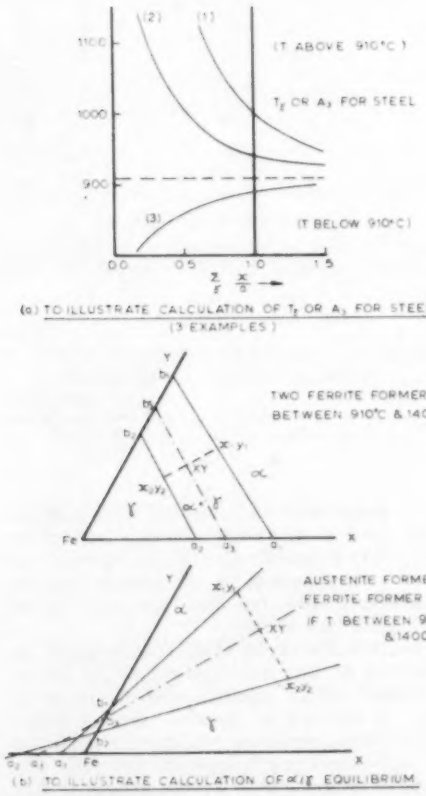
$1-C^{\alpha}/1-C^{\gamma} = \exp. -\Delta F_{Fe}/RT$ ..... (2)

(β = 1 for substitutional, 3 for interstitial solutions).

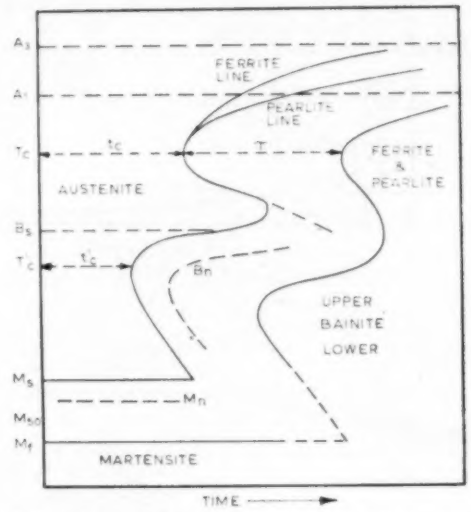
Here ΔH is positive for ferrite formers and negative for austenite formers.

ΔF_{Fe} = Difference in free energy between α and γ iron. (The writer had previously used the opposite sign convention[5] but the above is more general).

It is, however, true to say that ΔH cannot be regarded as constant over an appreciable range of temperature although in some cases agreement between calculated and observed γ loops was found to be reasonable assuming that ΔH was constant as a first approximation. Zener used two parameters in a later treatment.[9] Later Kauffmann gave a more detailed thermodynamic treatment and was able to suggest a reason for the minimum in the γ loop in the system Fe–Cr.[10] In effect the equilibrium reverses because some of the terms in the thermodynamic equations are small and vary differently with temperature. We can say that chromium is a weak ferrite former and any similar weak ferrite formers (if they existed) would tend to show a γ loop minimum.



5 *Calculations for low-alloy steels including austenite/ferrite equilibrium*

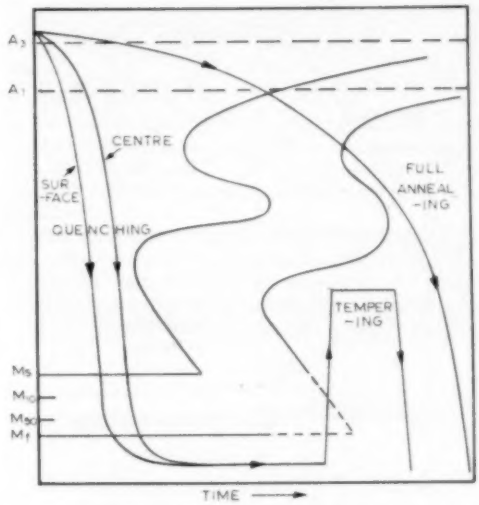


6 *Basic features of isothermal transformation diagram*

This point about the weak effect of Cr will be appreciated by reference to fig. 4 where we show ΔH values obtained from maximum solubility or from suitable points on the diagram for depressed transformations. This quantity ΔH can be regarded as a measure of the 'relative strength' of the alloy element—notwithstanding the above reservations about its variation with temperature. It would perhaps be possible to take the accurately established binary diagram as a base and use equations such as the above to measure the variation of ΔH with temperature. From a practical point of view, however, we should be more interested in ascertaining whether there is any possibility of extrapolating from the binary systems to actual steels, and this point deserves more consideration.

From this point of view it should be possible to make use of diagrams such as fig. 2 to estimate the

effects of individual alloy elements and then to combine these effects in a formula. The equations would be linear to a first approximation, and deviations from linearity could be taken account of by the use of additional terms probably involving



7a *Two traditional heat-treatment procedures seen in relation to the isothermal diagram*

products of concentrations. The writer has pointed out elsewhere[11] that if equations such as (1) above apply in ternary or higher alloy systems and equation (2) generally represents the ratio of iron concentrations in the two phases, then providing interactions between alloy elements are small or otherwise the solutions are regarded as 'dilute' then it follows that isothermal boundaries are straight lines in ternary systems, planes in quaternary systems or hyperplanes in higher order systems. The equation to a plane has the general form $(x/a) + (y/b) = 1$ and the hyperplane

$$\Sigma x/a = 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

for any number of terms. Such an equation would apply either to the α boundary or the γ boundary—in the latter case this is the A_3 point for the steel.

The equation (3) represents a phase boundary but in general a given alloy does not lie on the phase boundary. For a steel even within a given specification we have an arbitrary set of composition co-ordinates. If, however, these are inserted in expressions such as (3) for a series of temperatures the sum may not equal unity but have values on either side. If then the sum $\Sigma\gamma$ for (say) the $\alpha+\gamma/\gamma$ boundary is plotted against temperature then we can read off the temperature T_γ (or A_3) for the steel. This procedure is indicated in fig. 5*a* and in principle is *a method of calculating minimum austenitizing temperatures.*

A further development follows and is indicated in fig. 5*b*. If an alloy or steel of arbitrary composition lies in the two-phase region $\alpha + \gamma$ at a heat-treatment temperature then it can also be inferred that if its composition is $XYZ \ldots$ then it lies on a hyperplane

$$(X/a_3) + (Y/b_3) + (Z/c_3) = 1 \quad \ldots\ldots\ldots\ldots \quad (4)$$

where $a_3 = \varepsilon a_1 + (1 - \varepsilon)a_2$

$b_3 = \varepsilon b_1 + (1 - \varepsilon)b_2$

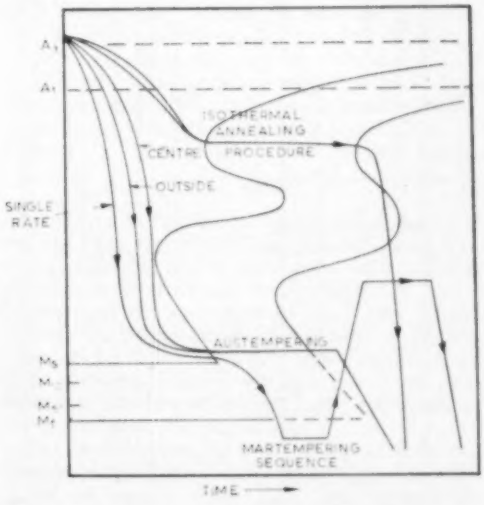
and $\varepsilon/(1-\varepsilon)$ = proportion of α/proportion of γ

The partition of alloy elements is given by

$$X = \varepsilon x_1 + (1-\varepsilon)x_2$$

Here the quantity ε can be found by a graphical method similar to that of fig. 5*a*. This procedure for calculating the constitution of phases in equilibrium could be of quite general application.

In practice the use of such methods is limited by the original assumptions and the extent to which



7b *Three special heat-treatment processes seen in relation to the isothermal diagram*

they are invalidated by interactions between alloy elements. It is considered, however, that a suitable combination of the thermodynamics with empirical relationships could enable these aspects of heat treatment to be put on a more quantitative basis.

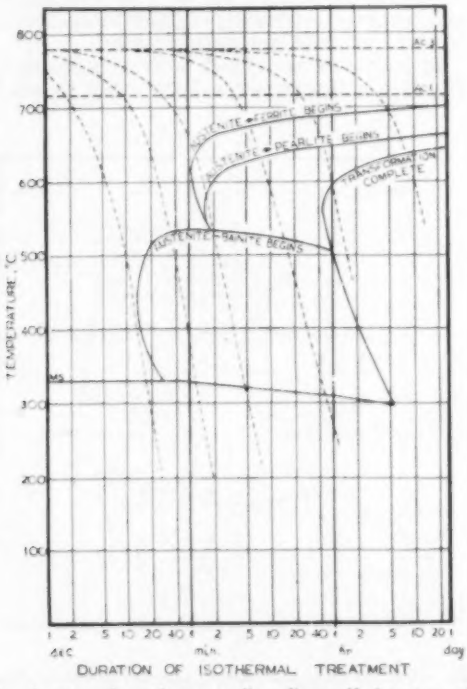
Transformation on quenching or sub-critical heat treatment

As used in industry carbon or low alloy steel is generally given a high temperature treatment which produces an approximation to equilibrium in the temperature region where austenite is stable, and then this process is followed by a treatment intended to bring the material into a useful condition for service structurally representing an approach to equilibrium below the eutectoid temperature. The conventional heat treatment processes are essentially two in number, *viz.*:

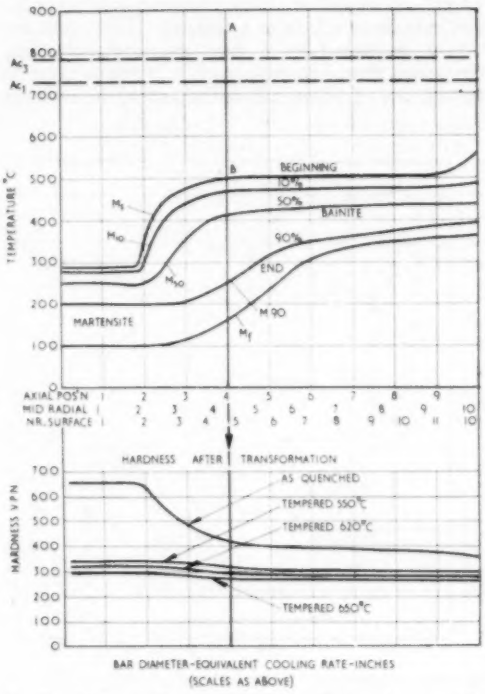
(1) Annealing followed by furnace cooling or cooling at other moderately slow rates, or

(2) Quenching followed by tempering.

The transformations which occur on cooling are best understood in relation to the structural changes which occur below the eutectoid temperature. These changes are conveniently summarized in terms of the isothermal transformation diagram or time-temperature-transformation (T.T.T.) diagram. The isothermal transformation diagram is



8 *A type of continuous-cooling diagram*[17] *(courtesy of the International Nickel Co. (Mond) Ltd. and the Tata Iron and Steel Co.)*



9 *Continuous-cooling transformation diagram (prepared by the United Steel Companies Ltd., R.D.D.)*

Type of steel: En 100							Cast no. W4921
Analysis weight %							
C	Mn	Si	Ni	Cr	Mo	S	P
0·39	1·35	0·24	0·65	0·48	0·17	0·042	0·040

		Grain size (A.S.T.M.	
Previous treatment as rolled	Austenitizing conditions 850°C. for 10 min.	McQuaid-Ehn	As quenched
	Oil quenching	7/8	

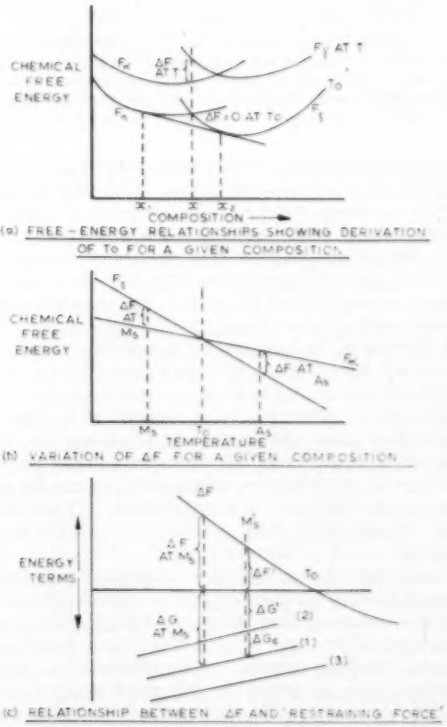
well known and provides an indication of the structures which could be obtained from a steel of particular composition or specification.

Fig. 6 shows schematically an isothermal transformation diagram and indicates the main changes which can occur. In some diagrams the overlap between the pearlite and bainite regions is considerable and the curve may then appear to be continuous without any bay. In this diagram too we can indicate, by curves between those representing the start and finish of a transformation, lines for transformation of a given fraction *n*, *e.g.* to martensite (M_n) or bainite (B_n).

From the present point of view the steel metal-

lurgist or user interested in heat treatment is aware that the shapes of these diagrams depend on the added alloy elements and are a guide to the capacity of the steel (of the chosen composition) to give a certain level of hardness or strength—taking necessary account of the effects of size. Reference to fig. 7*a* shows how the two conventional heat-treatment procedures relate to this diagram. Incidentally fig. 7*a* brings out the point that the inside of a piece of steel, say a bar, effectively cools at a slower rate than the surface and in the course of cooling is therefore nearer to the 'nose' of either the pearlite or bainite 'C curve.' Fig. 7*b* shows three other heat treatment processes in relation to the same diagram —indicating the cooling (and in one case re-heating) stages by which a given transformation product is achieved.

The hardenability of a steel is clearly related to the extent to which a practicable cooling rate just misses the nose of either the pearlite or the bainite C curve according to the relative positions of these curves. Hence the concept of 'pearlitic hardenability' and 'bainitic hardenability.' Holloman and Jaffe, for example, give a method for calculating such quantities (*e.g.* table on p. 200).[12] Their measure of hardenability is similar to that of Grossman's. The formulae state that a bar will contain almost no pearlite at the centre if its diameter in inches is $0{\cdot}254 \times \sqrt{\%}C$ and 50% pearlite $0{\cdot}338 \times \sqrt{\%}C$ in inches. The bainite nose is just missed for $0{\cdot}272\ \sqrt{\%}C$ and $0{\cdot}494\ \sqrt{\%}C$ respectively. To take account of the effect of other alloy elements these diameters must be multiplied by factors for each alloy element (assumed to act independently) of the form:—$(1 \pm \text{const.} \times \%$ alloy element). Generally the positive sign applies so that for most alloy elements hardenability is increased—sulphur and cobalt appear to be the only common exceptions.


CHEMICAL FREE ENERGY
COMPOSITION
(a) FREE-ENERGY RELATIONSHIPS SHOWING DERIVATION OF To FOR A GIVEN COMPOSITION
CHEMICAL FREE ENERGY
TEMPERATURE
(b) VARIATION OF ΔF FOR A GIVEN COMPOSITION
ENERGY TERMS
(c) RELATIONSHIP BETWEEN ΔF AND 'RESTRAINING FORCE'

10 *Schematic representation of factors determining Ms temperature for a steel of given composition*

Relationships of this kind are empirical but as the scientific understanding of the subject develops they may eventually be interpreted in adequate theoretical terms or replaced by more correct formulae. Such interpretation is, however, very difficult. It will be appreciated by reference to fig. 6 that, if we knew the temperature T_c at which nucleation reaches the stage for transformation itself to begin and proceed by a normal diffusion process—generally diffusion of carbon—and if we know the time t_c we have the two basic quantities for the position of the pearlite C curve. When the C curve for commencement of reaction has been so defined it may proceed according to a fairly simple law especially if only the diffusion of carbon is involved. Zener[13] for example showed that the velocity of transformation was represented by

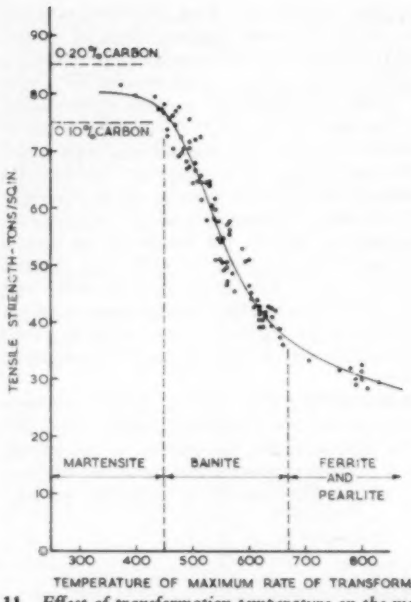
$$V_B \propto (T_c - T)^2 \exp. -Q/RT \quad \ldots\ldots\ldots\ldots (5)$$

where Q is the activation energy for diffusion of carbon. The time τ for completion of transformation is related to this velocity and since a diffusion distance is involved one would expect to find a dependence of τ on austenitic grain size. Alternatively the expression (5) can be seen to give the shape of the C curve for any time (fraction of τ). The austenite : pearlite reaction has been considered in detail by Mehl and Hagel[14] and reference should be made to their article.

As t_c and T_c define the nose of the C curve for the pearlite transformation, so also would $t_{c'}$ and $T_{c'}$ define the bainitic nose. The upper part of the bainite transformation which is horizontal or nearly so can be defined by a temperature referred to below. Otherwise it is clear that hardenability should be explicable in terms of the times t_c and temperatures T_c which in their turn are functions of the alloy elements. During the time t_c nucleation must be taking place in some way and yet the transformation product cannot have begun to form as a discrete phase.

During this period of time diffusion of carbon can evidently occur. The more limited diffusion of other alloy elements is also possible. The radical effect of these elements in altering the hardenability could thus be by reducing the rate of diffusion of carbon itself or by retarding the creation of critical nuclei in some other way. The precise mechanism is difficult to explain but there is evidence in certain cases. For example, Irvine *et al.*[15] have provided an explanation of the effect of boron on the hardenability of low-alloy steel containing small additions of that element. Here, however, it is the ferrite which begins to form before the pearlite which is retarded. Since this ferrite nucleates at the austenite boundaries it is supposed that the boron which has tended to concentrate at and near these boundaries has retarded the diffusion of carbon away from the ferrite forming in these regions. This example may, therefore, be regarded as a somewhat special case but the same kind of principles may be relevant generally.

A further complication of the subject arises from the fact that an isothermal transformation diagram has been derived by a somewhat different procedure from that followed by a steel in an industrial heat treatment. The changes that occur during cooling rather than at a constant temperature, define a continuous cooling diagram which consequently bears a closer relation to the actual process. Such a diagram may be regarded as a distortion of an isothermal transformation diagram and the difference is sufficient to justify the expenditure of effort to establish separate continuous cooling diagrams. Methods for determining such diagrams have been described.[16] A type of diagram is shown in fig. 8 (described by Narayan and Mayer[17] and a diagram for an alloy steel in fig. 9. For this steel similar diagrams exist for water quenching on the one hand or air cooling on the other. In the latter diagram there is an additional region showing the formation of ferrite and pearlite.



11 *Effect of transformation temperature on the mechanical properties. The rate of cooling employed for these results is equivalent to air cooling ¾ in. dia. bar (courtesy of the Iron and Steel Institute)*

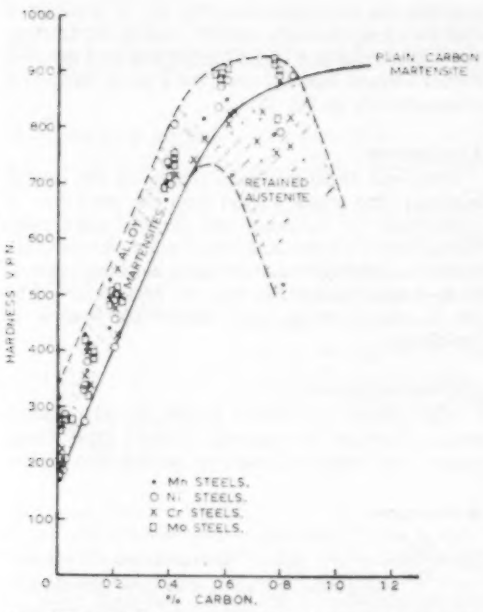
Martensite and bainite transformation temperatures

The martensite transformation itself is of great interest from many points of view not least in connection with the mechanism and crystallography. From the present point of view, however, the kinetics and thermodynamics are of more direct concern. These aspects have been fully reviewed by Kaufman and Cohen[18] and discussed recently by Owen and Gilbert.[19]

The basic principles which determine the transformation to martensite are indicated in fig. 10 and may be explained as follows:

In an iron alloy system, say iron-carbon, the equilibrium between austenite and ferrite is represented by free energy curves such as those shown in fig. 10*a* for a given temperature. This free energy is the chemical energy which determines equilibrium between two phases and at a given temperature the compositions of the two phases in equilibrium is given by a common tangent. These compositions are denoted by x_1 and x_2. Any alloy in between whatever its initial condition will approach equilibrium at the temperature in question. Now at this temperature there will be one alloy of composition x which happens to lie at the intersection of the two curves. Alternatively if, instead of breaking down to α and new austenite, according to the diagram an austenite of this composition chan ges to a ferrite α', of the same composition, it can do so without any diffusion of alloy element. Hence we have at this point only a metastable equilibrium between γ and α' for which, at T_o, $\Delta F^{\alpha' \to \gamma} = 0$. At other temperatures an alloy (or steel) of the same composition would transform to α' without diffusion and the corresponding finite free energy difference ΔF unequal to zero. For a given steel therefore there is one temperature T_o. As shown in fig. 10*b*, however, this is above the Ms temperature and, indeed, lies between Ms and As, the latter being the corresponding temperature for the reverse transformation.

The reaction thus does not occur as soon as the



12 *Effect of alloying elements on the hardness of martensite (courtesy of the Iron and Steel Institute)*

relevant ΔF is less than zero and a finite difference is required. The reason for this is indicated in fig. 10*c*. There is an amount of energy ΔG which has to be provided in order to cause the growth of a nucleus or embryo which is believed to be already present in the austenite. This quantity includes the surface energy, elastic strain energy and any other energy which the ΔF (chemical) driving force must overcome. An applied stress can, however, affect the transformation. It can provide an amount of strain energy, here represented by ΔG_s which can either act with or against ΔG. Thus, unaxial tension or compression will raise Ms by reducing ΔG in this way and so reducing the chemical free energy to be supplied—these conditions are represented in fig. 10*c* by $\Delta F'$, $\Delta G'$ and M_s'. A hydrostatic pressure, on the other hand, lowers the Ms temperature.

Without externally applied stress the strain energy term ΔG is of the order of 300 cal./mol. and appears to be independent of carbon content. Because ΔF is a function of carbon content one would expect the Ms temperature also to depend on carbon content which, in fact, it does. Similarly one would expect it to depend on the contents of alloy elements. The expressions for ΔF in a binary iron alloy system may contain linear and less important second power terms in the concentration of the alloy element. Reference to fig. 10*b* suggests that Ms will be an approximately linear function of composition. This is the reason for the approximate validity of formulae for the Ms temperature in terms of alloy content. A number of such formulae have been proposed and we may refer for example to formulae derived for a group of low alloy steels by Stephen and Haynes.[20]

$$M_n = K_n - 444C - 33Mn - 17Ni - 17Cr - 21Mo \ldots . (6)$$

(n indicates fraction transformed)

where, for M_S, K = 561

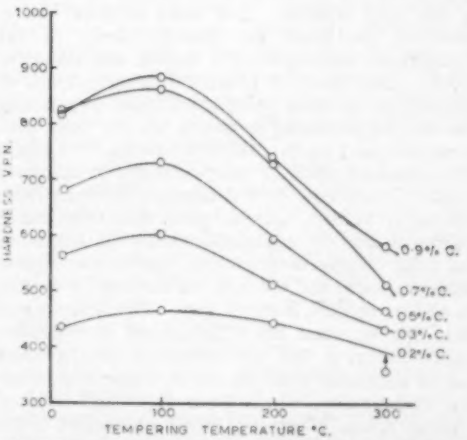
M_F, K = 346

with intermediate values for temperatures between. We note that carbon has much the most pronounced effect.

The same authors, and others, have given similar expressions for the bainite formation temperature Bs or Bn temperatures. Bs is the approximately horizontal (athermal) part of this transformation in fig. 6. In this respect the transformation is similar to the martensite. Here, however, the expression ΔF must have an additional term due to an entropy change resulting from diffusion of carbon whilst the ΔG term is probably much smaller and may even be negligible. The foundations of a quantitative treatment of the subject have therefore been laid.

Relationship of structure with properties

Only brief consideration can be given here to the interesting problem of how the structure determines the strength. The main question is the connection between hardness, yield point, proof stress, or tensile strength (*i.e.* the technical measures of mechanical strength) and the structure. It is



13 *Effect of low-temperature tempering on the hardness of varying carbon martensite (for 2 h. tempering)*

acknowledged that there is a general tendency for ductility to bear an inverse relationship to these properties. In many cases the aim of alloying and heat treatment has been to make the best compromise for a particular application.

Perhaps the most significant relation is one which states that strength is inversely proportional to the square root of the grain size. This relationship due to Petch[21] has been frequently used in discussions of the strength of metals. The most general expression is:

$$\sigma = \sigma_0 + k.d^{-\frac{1}{2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

where σ_0 and k are constants (*a*) for the material and (*b*) given the material, for a given measure of strength, *e.g.* yield point.

The next principle involved here is that the grain size decreases in the pearlite or bainite transformation region as the temperature falls. Hence, in the case of an individual steel the strength goes up as the temperature of transformation falls. This is exemplified in a diagram derived for a low-alloy steel containing Mo and B and described by Irvine and Pickering.[22] This diagram—fig. 11—shows the relationship and indicates that a wide range of strengths can be obtained from a single material.

The effect of alloying elements on strength as such may be partly due to solid solution hardening but their major effect is via the hardenability, by making transformation possible at lower temperatures as, for example, by removing the pearlite C curve to longer times so that at a given cooling rate a steel passes into the bainitic region. Here it transforms at lower temperatures the more the bainite C curve has been retarded or Bs lowered.

In fig. 11 the curve is shown extending into the martensite region but in this case the information is not very definite. The same authors[23] have, however, examined the general causes of the strength of martensite in a carbon and low-alloy steels. One result of interest here is that just as carbon has the most pronounced effect on lowering the Ms temperature, so also it has the most pronounced effect on the hardness—see fig. 12—where the additional effect of alloy elements is relatively small. There may be a connection between these effects of carbon, *i.e.* the grain size dependence continues into the martensite region. A bainite of the same composition, however, has a considerably lower hardness and the slope of the line for bainite in carbon content is much less. The difference is thus due to some other factor and the simplest interpretation is that the carbon in solid solution has an additional effect on the hardness by producing tetragonality, which leads to a high level of internal strain. There is a very fine structure in the martensite which would ensure an appreciable grain size effect but the internal strain effect probably accounts for the steep rise in fig. 12. It is admitted that very few steels are actually used in the martensite condition, but a higher initial hardness means a higher level of final hardness for a given tempering treatment—as in fig. 13.

Conclusion

Obviously there are many aspects of the subject outlined here which should help the steel user to understand his materials and employ them more effectively. It is realized that further development is needed although it has certainly not been possible to do justice here to all that has been achieved so far in this complex and interesting branch of metallurgy.

Acknowledgment

The author is indebted to Mr. F. H. Saniter, O.B.E., Director of Research, United Steel Companies Ltd., for permission to publish this article.

References

(1) E. C. Bain, 'Functions of the alloying elements in steel,' A.S.M., 1939.
(2) W. Crafts and J. L. Lamont, 'Hardenability and steel selection,' Pitman, London, 1949.
(3) J. S. Vatchagandhy and others, *Tisco*, 1958 (July/October), **5**, (3/4), 86.
(4) F. Wever, *Archiv fur das Eisenhüttenwesen*, 1928/9, **2**, 739; *Mitt. K-Wihl.-Inst. Eisenforschung*, 1931, **13**, 193.
(5) K. W. Andrews, *Metal Treatment*, 1952 (October and November), **19**, 425, 489.
(6) C. Zener, *Trans. A.I.M.E.*, 1946, **167**, 513.
(7) W. Oelsen and F. Wever, *Archiv fur das Eisenhüttenwesen*, 1947/8, **19**, 97. W. Oelsen, *Stahl und Eisen*, 1949, **69**, 468.
(8) F. W. Jones and W. I. Pumphrey, *J. Iron St. Inst.*, 1949, **163**, 121.
(9) C. Zener, *Trans. A.I.M.E.*, 1955, **203**, 619.
(10) L. Kauffman, *Ibid.*, 1959, **215**, 218.
(11) K. W. Andrews, *J. Iron St. Inst.*, 1956, **184**, 414.
(12) J. H. Holloman and L. D. Jaffe, 'Ferrous metallurgical design,' John Wiley & Sons, N.Y., Chapman & Hall, London, 1947.
(13) C. Zener, *Trans. A.I.M.E.*, 1946, **167**, 550.
(14) R. F. Mehl and W. C. Hagel, 'Progress in metal physics' (edited by B. Chalmers and R. King), 1956, **6**, 74.
(15) K. J. Irvine, F. B. Pickering, W. C. Heselwood, and M. Atkins, *J. Iron St. Inst.*, 1957, **186**, 54.
(16) W. Steven and G. Mayer, *Ibid.*, 1953, **174**, 33.
(17) S. N. Anant Narayan and G. Mayer, *Tisco*, 1958 (July), **5**, (3), 120. (see ref. 3).
(18) L. Kaufman and M. Cohen, 'Progress in metal physics,' 1958, **7**, 165.
(19) W. S. Owen and A. Gilbert, *J. Iron St. Inst.*, 1960, **196**, 142.
(20) W. Steven and A. G. Haynes, *Ibid.*, 1956, **183**, 349.
(21) N. J. Petch, *Ibid.*, 1953, **174**, 25.
(22) K. J. Irvine and F. B. Pickering, *Ibid.*, 1957, **187**, 292.
(23) K. J. Irvine, F. B. Pickering, and J. Garstone, *Ibid.*, 1960, **196**, 66.

Exhibition of laboratory equipment

Britain spent nearly £500 million on research in 1958–59—even more in 1959–60, for which returns are not yet complete—and is expected to spend considerably more in the current year. To hold a world lead in technology demands continual development of a variety of new equipment and techniques.

The latest developments in nearly all fields of advanced technology will be shown at the Laboratory Apparatus and Materials Exhibition from June 19–22, at the Royal Horticultural Society's New Hall, Westminster. Seventy of the leading British and overseas firms manufacturing laboratory instruments and materials will be exhibiting and 12 lecturers of international repute will speak in the lecture hall during the exhibition.

Performance of forging presses

H. STERN, B.Sc.(Eng.), A.M.I.Mech.E.,
and Cmdr. J. I. T. GREEN, O.B.E., M.I.Mech.E., M.I.Mar.E., R.N. (Ret.)

Trials on presses with direct, steam-intensifier, and accumulator drive are discussed. The steam-intensifier drive is considered obsolescent, and a comparison given of the other two types. It is concluded that the full benefits of fast-acting presses can be realized only by improvement in manipulation and the development of position control. This article, concluded in this issue, is based on a paper presented at a meeting of the Institution of Mechanical Engineers in the University, Sheffield, last February. The authors are with the Plant Engineering and Energy Division, British Iron and Steel Research Association, London

continued from last month

1,750-TON ACCUMULATOR PRESS. This is a recently commissioned press, which can be expected to be in good condition. Also, the accumulator system should give a rapid build-up of pressure, with a consequently high initial rate of penetration. The press has also been designed to give fast lifting and lowering and good results might therefore be expected.

Four examples from the trial results have been included in table 2. The rates of penetration for the 1,535-ton stroke are disappointing, no advantage being derived from the accumulator, while those for the 1,020- and 920-ton strokes are comparatively fast. The 895-ton stroke has been included for comparison with the 920-ton stroke to show how poor operation can substantially worsen the results. This is the only departure in table 2 from the general policy of choosing the examples from the better results. Both the facts that the press is comparatively fast acting and that the operating teams are relatively new to it make the results more susceptible to variations in operating skill.

The reasons for the low rate of penetration during the 1,535-ton stroke have been analysed. The most obvious one of these is that the press is working near its maximum load, and that the pressure drop available to force the water through the control valve is comparatively slight. These conditions are further aggravated by the line pressure being 300 lb./sq. in. below nominal at the beginning of the stroke, this difference increasing to 450 lb./sq. in. at the end of the cycle, and by appreciable unnecessary throttling at the control valve, as evidenced by the final position of the valve rocker shaft in fig. 8. Immediately prior to decompression the difference between line pressure and cylinder pressures is about 200 lb./sq. in. and obviously an appreciable increase in speed would have been obtained, had the line pressure been up to its full nominal value.

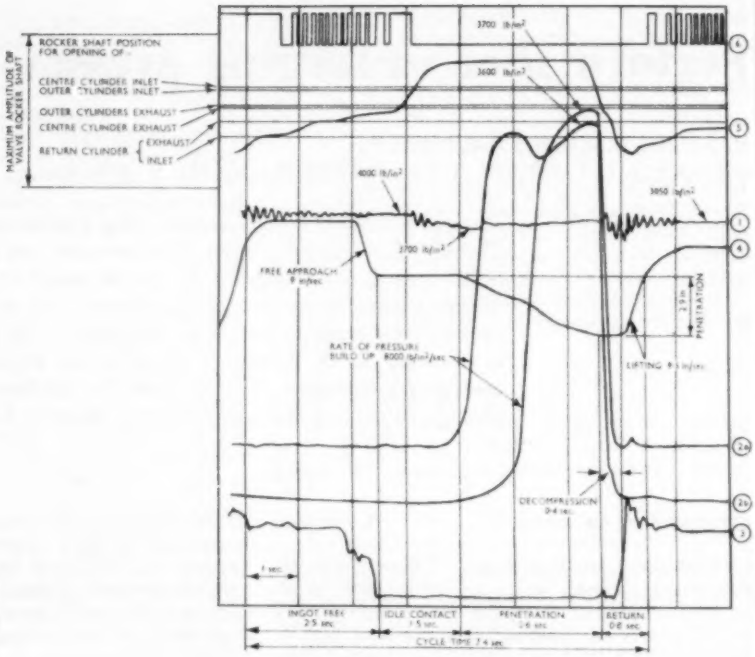
Further important factors slowing up forging are the delays in building up pressure in the cylinders, especially the lag between the centre and outer cylinders.

For almost $\frac{1}{2}$ sec. after the valve rocker shaft reaches the position where the inlet valve cracks open during slow-speed tests there is little, if any, perceptible pressure rise in the outer cylinders. In the case of the centre cylinder this interval increases to about $\frac{3}{4}$ sec. Thereafter, even though the pressure rise is unmistakable, the rate of pressure rise increases only very gradually to the rate at which most of the pressure rise eventually takes place. The rate is particularly slow in the case of the centre cylinder.

The authors are not in a position to give an entirely satisfactory explanation of this, as it would require a detailed investigation to arrive at complete and final conclusions. Amongst the more plausible reasons advanced are the following:

(1) Prefill or exhaust valves sticking in open position.
(2) Air in the cylinders.
(3) Wrong tappet adjustment.
(4) The complicated construction of the inlet valves.

No records of the individual valve motions were taken. Therefore the only comment in connection with valve stickage which can be made is that both



8 *1,535-ton cycle accumulator press*

1, Line pressure. 2a, Pressure in outer cylinders. 2b, Pressure in centre cylinder. 3, Pressure in lifting cylinders. 4, Crosshead movement. 5, Rocker shaft. 6, Bite (each pulse = 1 in.)

prefill and exhaust valves rely on springs for their return motion.

Some support for the other reasons listed comes from the fact that during the trials the inlet valve for the centre cylinder was changed for one of a different material, and that the tappets were re-adjusted at the same time. Subsequent to this, the performance of the centre cylinder was more in line with that of the outer cylinders, with a very appreciable cut in the lag between the cylinders.

As the cylinders had to be emptied during the valve change and subsequently bled, it is possible that some air had been eliminated. Air present in the cylinders could be responsible for a slow pressure build-up.

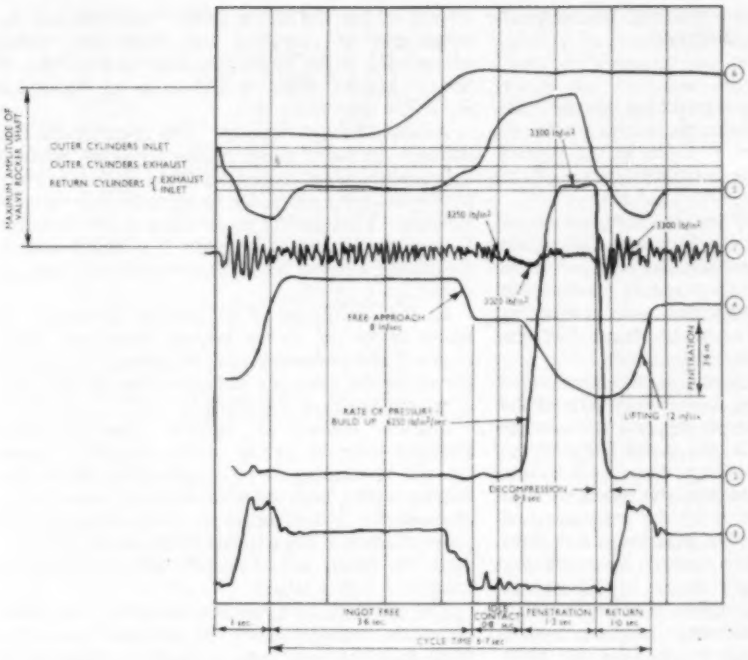
The effect of the tappet readjustment was mainly to have the centre cylinder leading instead of the outer cylinders, and to increase somewhat the dead zone between the closing of the exhaust valves and the opening of the inlet valves. It is difficult to see how this could affect the pressure build-up in the cylinders.

The inlet valves consist of three concentric-seated valves, so arranged that they lift in succession, starting with the smallest centre valve, in order to reduce the pressure difference against which the larger valves have to be lifted. If the passages through which the water has to pass to go through the inner valves are restricted, and if the lift between the successive stages opening is comparatively large, this may account for slow pressure build-up. Individual differences due to machining tolerances or wear may account for the difference in performance with different centre-cylinder valves.

With the exception of the stroke in the 1,500-ton group, results were available subsequent to the valve change and tappet readjustment, and these have been quoted in table 2.

The improvement in the rate of penetration in the 1,020-ton stroke compared with the 1,535-ton stroke is mainly due to the lower load combined with a larger valve opening, and only partly due to the reduction in the lag between cylinders. The performance during the 1,020-ton stroke would have been better still, if the line pressure had not been 1,000 lb./sq. in. below the nominal value, owing to inadequate air-loading of the accumulator.

The line pressure was measured at the entry to the valve block. Despite the fact that owing to site conditions the pumps and accumulator were situated 140 ft. from the valve block, the pressure measured must also be the accumulator pressure in between forging strokes, when there is little or no flow. The pressure drop from accumulator to valve block can therefore be inferred from the dip and recovery of the trace during and after the penetra-



9 *920-ton cycle accumulator press*
1, *Line pressure.* 2, *Pressure in outer cylinders.* 3, *Pressure in lifting cylinders.* 4, *Crosshead movement.* 5, *Rocker shaft.* 6, *Bite*

tion. The fact that there is very little recovery after the end of the penetration indicates that the final rate of penetration is not appreciably affected by the pressure drop in the pipeline from the accumulator.

The 920-ton stroke in table 2, where only two of the press cylinders are used, is illustrated in fig. 9. This shows the shape of the penetration curve when the complication of the phasing of the cylinders is absent. For comparison purposes the 895-ton stroke is included in table 2 from the same pass. The conditions for the two strokes are comparable, and the difference in average rates of penetration is due only to the slower rate of vavle opening in the case of the 895-ton stroke. This gives a very good indication of the importance of the human factor with a fast-acting press. Indeed, operation on two cylinders only is resorted to for the sake of keeping the rate of penetration down to controllable limits.

A comparison of the ingot free times for these two strokes, as well as those for the other presses, stresses the importance of efficient manipulation and co-ordination within the team.

A manipulator was used with this press which saves manpower and rebalancing as the ingot elongates, but ingot free times tend to be a higher proportion of the cycle time than for the presses working with porter bars (between 30 and 55% for the cogging operations analysed). The manipulator driver is also badly placed to judge the movement of the ingot which is terminated in the same manner as with porter-bar operation, that is, by the descent of the top tool. As usual, this produces considerable variations in bite.

1,200-*ton direct-acting press.* This is the smallest of the presses discussed in this paper, and only results near its maximum load lend themselves for comparison with the results obtained on the other presses. Figures for only one cycle at about 1,000 tons load have therefore been quoted in table 2, and this cycle is also illustrated in fig. 10. It should be noted that the time scale in fig. 10 differs from that in other diagrams.

This is the only case where the actual results attain the theoretical optimum performance of the press as calculated from the particulars in table 1, and is in marked contrast with the other direct-acting press where large volumes of fluid are lost through the relief valve, etc.

Automatic prefilling cuts the idle contact time to the insignificant fraction of a second required to shut the prefill valve, and the time wasted while the operator reacts and moves his control from the prefill to the forge position is eliminated.

Fast decompression and a very high return speed cut the return time to a minimum.

Discussion

Some of the features mentioned in the trial results are common to all presses, others are due to individual design features or faults in the presses concerned, while some are inherent features of the type of drive.

Features common to all presses. The effects of compressibility and elastic deformation fall within this group. The only qualification here is that to limit the volume subject to aternate compression and decompression, intensifiers and pumps for direct drive should be close to the press. There is more freedom in siting the accumulator.

The effect of speeding up presses also raises common problems, owing to the limitations of the human operator, who cannot respond fast enough to take full advantage of the capabilities of the press. In contrast with rolling, where each reduction is preset by roll position, the limits of each forging stroke are governed by the judgment and response of the operator. In practice, a fast press will often be deliberately slowed down by the operator, or, if the controls do not readily permit this, accuracy is likely to suffer. The replacement of hand control by automatic position control would enable the full potentialities of a fast press to be realized, thus increasing the amount of work done during the heat. Position control for a slow-acting press will have no significant effect on output, but may allow the use of less skilled labour.

In common with rolling operations, however, the total manipulation time, which includes time between passes, is a very high proportion of the time required for the complete operation. Improvements to presses, therefore, are of little benefit unless matched by improvements in manipulation. Both speedy operation and position control are again required. To replace the porter bar by a manipulator is in itself not enough, as a comparison of the results shows. It is beyond the scope of this paper to deal with this part of the problem.

The problem of rapid valve opening is again common to all presses. Balanced spool valves as commonly used for oil circuits have an advantage here over the seated valves usually used for water, which have to be opened against the resistance of fluid pressure. Provision for progressive throttling also places the valve at a disadvantage, but a possible solution here is to provide two valves, one for fast and one for slow working, with only the latter having special provision for throttling.

For quick response, the control valves should be close to the cylinders. One solution is long pilot lines from control desk to valves, another remote control by electric means. An attractive solution is offered by the pull-down press. This also has the advantages of requiring less headroom, better accessibility of the hydraulics, and the reduction of the fire hazard where oil is used, as the hydraulics are below floor level.

Individual design features. The considerable loss through the relief valve on the 2,250-ton press is an example of an individual fault, although water hydraulics are more prone to valve trouble than oil systems. The slowing down effect of the feedback linkage on the intensifier press is a design feature frequently adopted but not essential to this kind of drive.

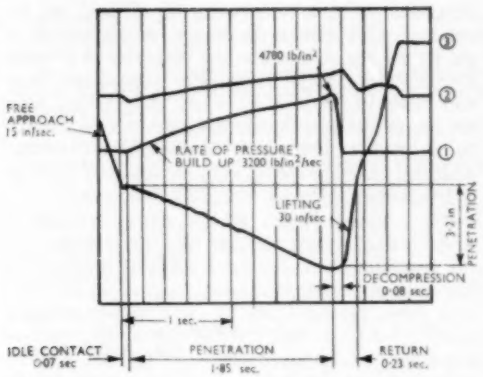
In the discussion of the results a number of faults shown up by the records have been mentioned. The disclosure of such faults, some unsuspected by the user, is a demonstration of the value of tests of the type described.

Features inherent in different types of drive. Features inherent in the steam-intensifier design are the limitation to the length of a continuous forging stroke, and the slow build-up and release of pressure. Valves might be made larger to improve the latter, but a highly compressible working fluid like steam will always be at a disadvantage compared with a liquid.

The problem of automatic prefilling, *i.e.* when no action is required by the operator to change from prefilling to forging, is easier to solve for the direct drive than for an accumulator system.

Some appreciable variation below the maximum pressure must be accepted with the air-loaded accumulator, if the air bottles are not to become unduly large, and if temperature variation has to be allowed for during operation.

Pressure losses between pump and press are mainly due to losses in the control valve. Reference to fig. 1 shows that it is possible to have a system for the direct drive where the fluid does not have to pass through a control valve during the forging stroke. This is not the case with accumulator drive, and some loss must be accepted here, especially with a valve designed for throttling to give speed control. This is not very serious, except when the press is operated near stalling point, and all possible load is required. Speed control for the direct drive can be accomplished by throttling through a bypass valve as in fig. 1, or, where there are multiple pump units, some of the units can be cut out. If one pump unit is of the variable delivery type, stepless variation can be obtained. Reduced speed is necessary for such operations as cutting, marking out, bending and straightening. Also, some heavy upsetting operations, otherwise requiring a larger press, can be done at rates less than normal speed and reducing pump output avoids large amounts of heat being generated at the relief valve of a direct system.



10 *1,010-ton cycle, 1,200-ton direct-acting press*
1, Pressure in main cylinder. 2, Pressure in return cylinders. 3, Crosshead movement

Estimated optimum performance

Because of individual faults attributable to the condition or adjustment of the hydraulic systems, and because ingots forged during the trials were not identical, caution must be exercised in comparing results in table 2.

To make a more valid comparison, table 3 has been compiled. The main assumptions are stated in the table. Both 85% maximum load and 3-in. penetration are fairly typical of the heavier work recorded. Three-inch penetration is also near the maximum obtainable on the steam-intensifier press. Operation without prefilling has been assumed to avoid making an arbitrary allowance for idle contact time. Such operation can only be sustained on the accumulator press if the upper limit of the stroke is closely and automatically controlled, as the pumps cannot deal with the increase in average demand caused by excessive free approach.

Table 3, although necessarily an estimate, is based on actual trial results as far as possible. The rate of penetration for direct-acting presses has been estimated from the pump output, making allowance for volumetric efficiency and the volume required to make up fluid compressibility and elastic deformation (see table 1). For the other presses the estimates are based on trial results where the required difference between line pressure and final main-cylinder pressure was obtained.

Choice of drive

The steam-intensifier drive has only mechanical simplicity to recommend it. Otherwise it is both slow, and wasteful in the use of steam, and it is therefore becoming obsolete.

The choice for a new press therefore lies between direct drive and accumulator system. The respective advantages and disadvantages of these drives have been discussed by previous authors, notably Sanderson and Frith,[6] and Elkan and Lewis,[7] while Towler and Wilkins have expounded the particular merits of oil hydraulic drive.[8] The purpose of the following contribution is to discuss the problem from the point of view of performance, but the other main points are also important and are worth recalling.

With an accumulator system it is possible to run several presses from a central water-power station, provided the presses are sited close together. This averages out the demand, and saves some pumping and accumulator capacity.

The accumulator system also allows several motions on a press and its auxiliaries to take place simultaneously, which is not easily possible with direct drive unless there are separate pumps, as the motion requiring least pressure would be completed first.

If several power stages are required on an accumulator press, by having a three-cylinder system, the centre ram must also play the role of the central guide stalk, but without the benefit of effective lubrication if water is used as hydraulic fluid.

The question of power consumption is not a clear-cut issue, despite the fact that all fluid has to be pumped up to maximum pressure in the case

TABLE 3 *Estimated optimum performance (for 85% maximum load and 3 in. penetration)*

Description of press	Load, tons	Approximate average rate of penetration in./sec.	Decompression time, sec.	Return speed, in./sec.	Free-approach speed, in./sec.	Minimum cycle time, sec.
2,250-ton, direct-acting ..	1,800	1½	0·2	3½	2	4·5
1,200-ton, direct-acting ..	1,000	1½	0·1	30	15	2·9
2,000-ton, steam-intensifier	1,700	1½	1·0	5	5	5·4
1,750-ton, accumulator ..	1,200—1,350*	3½	0·3	12	12	2·4

* Depending on water level in accumulator (see table 1)

Assumed conditions: Forging low-alloy easily worked steel; best possible operation and adjustment of valves; no use of prefilling, except for 1,200-ton press where this was automatic; 1 sec. ingot free time allowed for manipulation; and crosshead at mid-position.

of the accumulator press, as the idling losses of the larger pumps required for the direct drive can be considerable.[9]

The question of working fluid also enters into the argument, as not many high-speed pumps have been developed for water. High-speed reciprocating pumps for water raise lubrication problems, while centrifugal pumps have large idling losses. Large accumulators with separating pistons are rare, and, although opinions are divided,[10] a separator piston with oil seems advisable to reduce absorption of gas. To prevent the risk of explosion, accumulators for oil are usually loaded with nitrogen. Other factors in this category are the reduced corrosion and wear with oil, the greater volumetric efficiency of oil pumps, and the fire hazard created with oil, if large volumes are kept under high pressure in an accumulator system. Leakage with oil is reduced, but is more objectionable.

Site conditions and other special considerations will also play a role in the choice of drive.

Turning now to the question of performance, it is found that both kinds of drive can have fast lifting speeds and quick reversal. It is therefore valid to make a comparison for performance purposes on the basis of average rate of penetration. Table 3 indicates that for the example chosen this rate of penetration is much greater for the accumulator press than for the direct-acting presses. Differences in the relative sizes of pumping plant are not significant. A pumping capacity of 400 gal./min. (actual output) is required in the case of the accumulator press to sustain repetitive strokes. The question arises whether it is cheaper to pay for an accumulator and its auxiliaries or to install more pumping plant. This brings one to the two questions which anybody installing a press for a given duty must ask himself:

(1) What rate of penetration is it economical to pay for? and

(2) Which is the cheapest way of obtaining it?

For the direct drive the pump output is also the peak output. For the accumulator system the pump output is only the average required for the cycle. If the proportion of the total cycle time actually spent pressing is very great, capital expenditure for the drive might more usefully go on pumps only, while if the pressing time is a smaller proportion, an accumulator is an advantage.

For a given average rate of penetration, the final rate of penetration, and hence the final load, will be greater for the direct drive. Therefore, direct presses must operate at higher pressure if they are not to be larger. In actual fact the maximum working pressure is limited for accumulator presses by the fact that the higher the pressure the less the difference in density between liquid and gas becomes. This affects the degree of absorption of gas by the liquid, and also the buoyancy of the float for the level control. For water a maximum pressure of about 2 ton/sq. in. is used in practice, while for direct drives a maximum pressure of 2½ ton/sq. in. or more is used. This difference, combined with the inevitable downward variation of pressure in the accumulator, should cover this point.

For cogging strokes of the type envisaged in table 3, trial results indicate that the average rate of penetration is about 2½–3 times as great as the final rate of penetration in the case of an accumulator press, provided that all cylinders are acting in unison. For a direct-acting press, the rate of penetration is approximately uniform for a given stroke, so that the final rate of penetration can be taken as being equal to the average rate. Forging research[11] indicates that for carbon steel at 1,000°C. a 25% increase in force produces a rate of penetration 3½ times greater, thus confirming the statement above.

Two other points must also be mentioned. The electric motors for direct drive are only operating at maximum load for a fraction of the cycle, and can be subjected to considerable overload. This reduces their size and cost. The size of the accumulator is governed by the longest continuous upsetting stroke required, and not by the proportion of the cycle time spent pressing. These two considerations must be borne in mind when comparing the capital cost of the two kinds of drive.

Conclusions

The trials have shown that many factors can contribute towards the slowing up of forging presses. Some of these can be rectified by appropriate adjustment, maintenance, re-design of valves, or other remedies within the scope of customary practice. Others demand the development of position control for press and handling plant, particularly as presses become faster.

The importance of parallel development of manipulators must be stressed, and the controls of press and manipulator should be interlinked for the development of automatic operation.

The choice of drive depends on numerous factors, but amongst the most important are the nature of the forging cycle and the performance required in any particular case.

Acknowledgments

The authors would like to express their appreciation of the help and facilities given to them by Darlington Forge Ltd., Thomas Firth and John Brown Ltd., Loewy Engineering Co. Ltd., and Towler Bros. (Patents) Ltd.

Appendix

Terms used in the paper for the various elements of the forging cycle:

Pass. A longitudinal pass consists of the axial movements and the pressing operations carried out between rotations of the ingot.

A rotational pass consists of the rotational movements and the pressing operations carried out round the circumference between longitudinal movements of the ingot.

Time for a pass. Time from the start of penetration in the first stroke to the end of the return time for the last stroke.

Stroke. Downwards movement of the top tool from the beginning of descent to the end of pressing.

Penetration. The travel of the top tool during the pressing operation, measured from the point of contact with the ingot.

Bite. The longitudinal movement of the ingot between consecutive strokes.

Ingot free time. The time during which the ingot is free to be moved under the tool.

Idle contact time. The time between the instant of contact of the top tool with the ingot and the moment when penetration starts.

Penetration time. The time the tools actually penetrate into the ingot.

Return time. The period from the beginning of decompression to the instant when the ingot is free to be moved under the tool for the next stroke.

Forging time. The sum of idle contact, penetration and return times.

Cycle time. The interval between the beginnings of successive penetrations, *i.e.* the sum of the ingot free time and forging time.

References

(1) P. L. Lillywhite, *J. Iron St. Inst.*, 1958, **190**, 394.
(2) P. L. Lillywhite and P. R. Hoggatt, 1956 BISRA Report PE/103/56, 'A technique for studying press performance, trials on a 2,250-ton forging press.'
(3) H. Stern and M. Bielec, 1957 BISRA Report PE/119/57, 'Performance trials on a 2,000-ton forging press at Thomas Firth and John Brown Ltd.'
(4) H. Stern and L. J. Chant, 1958 BISRA Report PE/N/127/58, 'Remote position control for 1,750-ton Loewy press.'
(5) F. H. and J. M. Towler, *Proc. Instn. mech. Engrs., Lond.*, 1952–53, **1B**, 420.
(6) J. A. Sanderson and J. G. Frith, *J. Iron. St. Inst.*, 1949, **161**, 231.
(7) R. M. L. Elkan and J. T. Lewis, *Ibid.*, 1956, **182**, 200.
(8) F. H. Towler and B. C. Wilkins, 1957 BISRA Report PE/N/11/57, 'Precision control of hydraulic forging presses.'
(9) Walter Dohrn, 1956, 'Der Energieverlust bei Hydraulischen Pressen,' paper published by Schloemann, A.G.
(10) J. G. Frith, *Proc. Instn. mech. Engrs., Lond.*, 1956, **170**, 185.
(11) V. Valorinta, *Werkstattstechnik und Maschinenbau*, 1958, **8**, 452.

Big savings from carbide injection

Extensive tests have shown that carbide injection equipment supplied by British Oxygen will enable the Aston works of Spartan Steels & Alloys Ltd. to make fuller use of scrap metal in producing stainless steel. With the carbide injection process the sulphur content of the raw material can be reduced to the required level without having to use relatively expensive pig iron.

Equipment consists of a carbide dispenser and a lance. Carbide is blown through the lance and into the melt by compressed nitrogen. Sulphur content in a three-ton melt can be reduced from 0·078 to 0·024% in 20 min., using 200 lb. of carbide and 200 cu. ft. of nitrogen. Other fluxing agents would take at least two hours at several times the cost.

At present Spartan Steels are using carbide injection on one three-ton furnace. Their second three-ton furnace will soon be employing the technique and ultimately both will be doing six melts a day using carbide injection.

Drop Forging Research Association

AT THE A.G.M. of the Drop Forging Research Association, held in Sheffield last month, Mr. R. Bennett, Smethwick Drop Forgings Ltd., was re-elected to the Council, and the following new councillors were elected: Mr. H. G. Brown, Firth-Derihon Stampings Ltd.; Mr. W. E. A. Redfearn, English Steel Forge & Engineering Corporation Ltd.; Mr. D. B. Russell, Smith & Sons of Saltley Ltd.; Mr. J. Shakespeare, J. Shakespeare & Co. Ltd.

In the course of his remarks the chairman, Mr. W. E. Golcher, mentioned that there were now 36 members of the Association. He commented that the report on the financial position was reasonably satisfactory for this stage in the Association's development, and paid tribute to Mr. R. G. M. Morgan, the chairman of the Finance Committee, and the members of the committee for their able stewardship. He also thanked all the members of the Council for giving up their time to the guidance of the Association, and in this connection he particularly mentioned Dr. C. J. Dadswell, English Steel Forge & Eng. Corp. Ltd., whose help had been invaluable to the Sponsoring Committee and to the council. Dr. Dadswell had found it necessary to retire from the Council and did not offer himself for re-election, but the chairman was glad to welcome in his place an old friend, Mr. W. E. A. Redfearn.

At the conclusion of his report, the chairman said that, owing to pressure of other business, he felt impelled to resign from the chairmanship. He thanked all the members for their support during the early stages of this venture, and expressed his confidence that the Association would grow vigorously in the years to come.

In moving the adoption of the chairman's report, Mr. J. H. Swain expressed the appreciation of the whole drop-forging industry to Mr. Golcher for his able and energetic chairmanship of both the Sponsoring Committee and the council.

At a Council meeting following the A.G.M., Mr. J. H. Swain, Stampings Alliance Ltd., was elected chairman of the Council in succession to Mr. W. E. Golcher, and the following were co-opted to the council: Mr. R. K. Johnson, Forgings & Presswork Ltd.; and Mr. A. L. Stuart Todd, C.B.E., J.P., National Association of Drop Forgers and Stampers.

Automatic solvent degreasing plant

FOR MANY YEARS, trichlorethylene and perchlorethylene have been recognized as being two of the most effective degreasants available to industry. They have proved of particular value in all kinds of engineering for removing from metal components everything from light machining oils to heavy grease coatings. Their effectiveness can vary, however, according to the means of application, and Dawson Bros. Ltd. have paid particular attention to this fact in the development of their range of automatic solvent degreasing plant.

The application of trichlorethylene or perchlorethylene can be by the suspension of the parts in solvent vapour, or a combination of this and immersion in boiling solvent. For superfine immersion cleaning, a transducer unit can be incorporated to set up ultrasonic vibrations in the solvent. Machines can be supplied incorporating solvent spraying sections. The choice of method will depend on the amount of grease, oil and solids on the parts being cleaned and the subsequent processing

Continuous solvent degreasing plant

In these machines the parts being handled are automatically taken through the degreasing process in carriers attached to a moving conveyor. Special loading and unloading facilities and other automatic handling devices are very frequently built into the machines to match up with existing handling arrangements already in use. Machines of this type are available incorporating solvent degreasing for use in conjunction with acid pickling, phosphate coating, bonderizing and other pre-treatment processes in any of a variety of combinations. Solvent spray sections can also be included in this plant.

The following details describe standard continuous operation machines incorporating a double immersion and vapour degreasing treatment, but most of the information also applies to single immersion vapour machines and machines for vapour degreasing only.

These machines are available for through or return operation as shown in fig. 1. With the through type, the parts are loaded by an operator at one end of the machine, and are carried through the treatment to be unloaded by a second operator at the other end. On the return type, the parts are loaded and unloaded at the same end of the machine by one operator.

The conveyor consists of two continuous chains fitted with evenly spaced carriers. These carriers can be in the form of cylindrical baskets or hanging fittings.

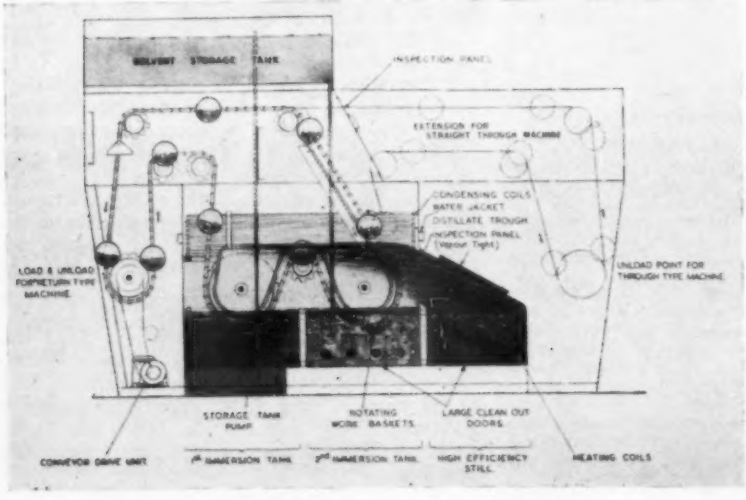
Cylindrical baskets. These baskets can be fixed to the chains for direct loading and unloading or detachable so that the basket of clean parts is removed from the conveyor and replaced with a basket of soiled parts. They are available either for rotation during treatment or for non-rotation, in the latter case they simply pivot retaining an upright position throughout their journey through the machine. The method of rotation is simple and foolproof. Sprockets on the ends of the baskets contact chains fitted along the course of the conveyor in the treatment zone, providing smooth rotation throughout the cleaning process. This revolving action moves the parts around inside the baskets, thus ensuring that the solvent flows freely over all the surfaces of the parts and penetrates all the deep drilling holes and other recesses. Where tumbling action might damage the parts, non-rotating baskets are recommended.

Hanging fittings are available as work-carrier baskets, fixed to the conveyor or as holders to receive removable trays specially designed for given components.

Drive. The conveyor is driven by an electric motor and reduction gearbox. On the larger machines a magnetic clutch is often fitted. Power transmission is through chains and sprockets.

Operation. The operator loads the carrier or places a loaded carrier into position and presses the starter button which indexes the conveyor, and all the carriers attached to it, through one pitch, bringing forward a carrier of clean parts to the unloading position; this is emptied or

continued on page 210



Operation of double-immersion vapour machine. Return-type machine is shown, and dotted section indicates straight-through type

Gear and pinion forging

W. W. COLLIER

This article is based on a paper given last year at a general meeting of the Drop Forging Association of Australia by whose courtesy it has been received. Mr. Collier was formerly forge superintendent, Borg-Warner (Australia) Ltd.

WITH COMPONENTS as highly stressed as spiral hypoid gears, forging is a vital part of the manufacturing process. In addition to the usual requirement of a forging such as structural uniformity, freedom from concealed defects, etc., there is the essential requirement of stability of grain movement. Gear teeth are developed to give localized contact, thus avoiding load concentration at toe and heel of the teeth in service.

During the heat-treatment process which takes place after final machining, the teeth of spiral hypoid gears tend to straighten in their length. Allowance has to be made during cutting to alleviate this condition so that an economical operation will exist in lapping and mating, and produce quiet gears. Movement in heat treatment does not favour gear or pinion, as both tend to move comparable amounts.

Consistency in the method of manufacture of a forging is a most important requisite, to ensure that only a minimum of lapping is carried out. Any change of method affects the grain and new markings result which cause production hold-ups and some rejected gears. In addition to forging flow line affecting the shape of gear and pinion teeth during heat treatment, the flatness and bore size of ring gears are also distorted in the same way.

Flow lines around the core axis of a gear and pinion must be symmetrical to obtain consistency from tooth to tooth.

Although certain basic rules are laid down for both gear and pinion forging, it has been found that each gear has to be assessed and conditions adjusted to produce a consistent grain-flow-line forging.

The amount of working in many forgings is often greater than that necessary to obtain optimum grain flow.

Hypoid-pinion forging requirements

To obtain the desired results in hypoid-pinion forging, the following basic comments are applicable:

Maximum stock gather in one blow should be 1·9 dia. preferably from a sawn end. Shearing has the effect of stretching the length of the billet beyond the 1·9 dia. Flash should be kept to the minimum as excess metal through the dies causes a conglomerate of flow lines.

Where the amount of metal in the head can be safely done in one blow, it has been found that the mushroom button effect occurring from this method causes distortion if not symmetrical. One overseas manufacturer has taken the precaution when making single blow pinions of drawing the bar to –0 and + 0·008 tolerance to ensure the button is symmetrical and only sufficient metal is used to fill the head.

Properly designed, well-filled cones in each pass cannot fail to give a perfect symmetrical upset forging. Each cone must be well-defined on the ends so that correct guiding is given to the next pass. It has been proved that excessive clearance on cone end allows the bar to buckle, especially when grip dies are worn.

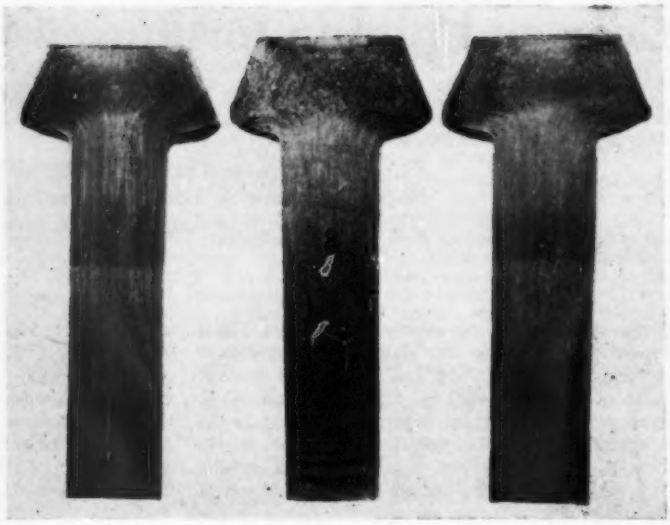
One of the main causes of excess stock in the pinion head is extended length of heats on early passes. This is usually done to get fast production rates to the detriment of quality grain flow, and has to be continually supervised during runs. This, of course, could only be a few pinions towards the end of each furnace heat cycle, but these are anticipated rejections in the machine shop gear-cutting lines.

Ring gear forgings

The manufacture of ring gear forgings to give a consistent grain flow line is more difficult to maintain because of the amount of metal that has to be moved to outer periphery of the forging.

All ring gears are made from square billet owing to cost restriction on the use of rounds, although research indicates that there is less distortion by their use.

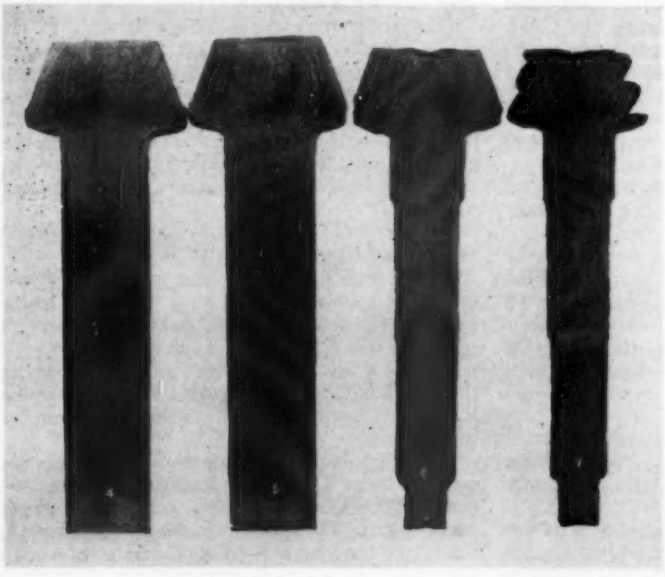
The selection of billet sizes is of utmost importance, as there is a marked tendency to use a too-small billet size in relationship to the crown wheel being forged. The smaller cross-section billet used, the longer the length of billet, the fibres of which,



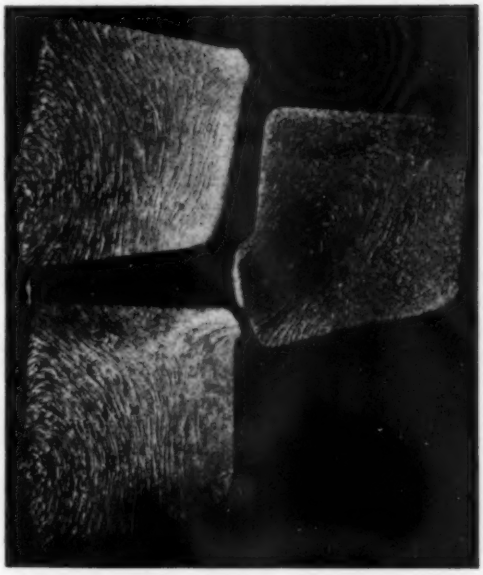
1 *Pinion manufacture (1) standard method with minimum flash (2) Maximum flash 1¼ in. dia. sawn bar (3) minimum flash from cropped bar. Note structure on right compared with well-defined grain on left*

when forged, are bent over; this is undesirable. Research seems to confirm that less distortion will result from compacted flow lines than from those that are bent in extreme hairpin style. This distortion is considered to result from the intrusion of the comparatively unworked core of billet into the tooth and machined areas of the machined component (fig. 3).

To determine on crown wheels the extent of this comparatively unworked core of billets intruding into machined and gear tooth area, tests were made. These consisted of boring out various cross-section SAE4620 billets and pressing in a 1 in. dia. mild steel insert, and then heating and forging in the normal way. These have shown, especially on web-type crown wheels, that the unworked core



2 *Pinion manufacture (4) Heavy flash—collapsing core, sawn end (5) Desired grain flow, sawn end (6) Machined—standard (7) Same as (6) with teeth cut*



3 *Comparison between correct section and undersize cross-sectional area billet for ring gears*

does intrude into danger areas. The 6¼ in. dia. crown wheel shown is made from 3 × 3 in. billet, which is considered the correct section, and the other sections illustrated are made from 2½ × 2½ in. billet and 2½ in. dia. (fig. 4).

Location of billets in a blocking impression are difficult because of the variation of corner radii, something which the steel mill does not seem to overcome. Experience on a large quantity of crown wheels has shown that a billet flattened to a parallel slug which fits snugly into a blocking impression, gives a consistent grain structure.

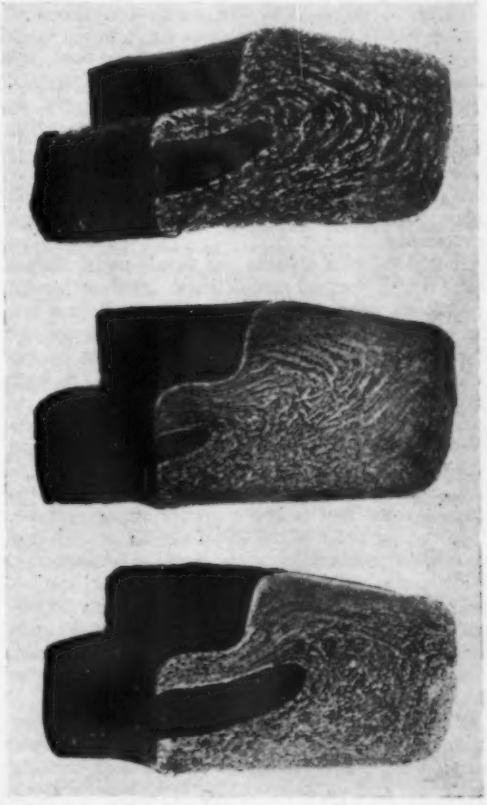
Distortion on final gears has also been traced to too much lubricant, especially on a forging press, creating a severe 'blow' in blocking impressions, which could not be seen in the final form. This seems to indicate that location from impression to impression on all gears should at all times be positive, at least on one diameter of the final form. This diameter should also be the machine fixture or jaw location for the machining operation, ensuring that the grain structure is running true in the final machine parts.

Dissection of many gear forgings in the machined form shows that often no consideration has been given by methods men, on first and subsequent machine operations, to ensure that grain flow required by the product engineer (and adhered to by the forger) has been achieved in the final component.

Gear forgings that have pierced holes for subsequent core drill operations, should be located for machining on the same area it was located for piercing. This ensures again that grain is concentric from the forging operation.

Upset pinions and main drives are sometimes located immediately behind the head of the components instead of on the head itself and on the end of the original bar. The area behind the head is affected by the moving die on one side not completely closing, leaving an offset error in the shank. Location on the head itself ensures that the component is turned true to the grain flow forged.

Ring gear and pinion forgings require greater care to prevent unusual distortion problems, but these requirements do not necessarily mean uneconomical forging production.



4 CENTRE *Crown wheel made from correct section (3 × 3 in. billet) compared with undersize billets*

Metallurgy in nuclear power technology

8. Coolant and containment problems in reactors

J. C. WRIGHT, B.Sc., Ph.D., A.I.M.

The metallurgy of nuclear power materials is developing on such a wide front and so rapidly that it is difficult for the non-specialist metallurgist to keep abreast with its scope. Dr. Wright, Reader in Industrial Metallurgy, College of Advanced Technology, Birmingham, outlines the subject in a series of articles appearing monthly in this journal since last July and concluded in this issue

LIQUID METALS. The two main applications of liquid metals in nuclear reactors are in liquid fuels, where a fissile component is associated with the liquid metal, and in liquid-metal coolant circuits. The chief advantages of liquid metals used in reactors are their good heat-transfer properties, irradiation stability, low vapour pressures at working temperatures and the fact that they are easily pumped round a circuit. Liquid fuels also offer the possibility of continuous processing.

For good heat transfer the liquid metal should have a high thermal conductivity. From a thermal diffusivity point of view it should also have a low specific heat and low density, but a high specific heat means that more heat can be carried by the coolant for a given temperature rise. A high density favours a smaller pressure drop due to friction in pumping the metal but this is overshadowed by the increased pumping power required generally to move denser liquids. Thus, in fact, a low-density liquid is favoured on balance and the ideal specific heat is also a matter of compromise. The boiling point of the metal should be high and its vapour pressure low at the working temperature. A low viscosity also minimizes power loss in pumping and the pressure developed by the electromagnetic pumps used for moving liquids depends on the current passing through the liquid metal. Thus the pumping efficiency increases with low-resistivity liquid metals.

The choice of liquid metals for individual reactor systems depends on the compatibility of the liquid metal with its containment system and canning materials and on the working temperature which must be considered in terms of the melting point of the liquid metal. Of the canning materials which are reasonably available, zirconium, niobium, vanadium stainless steel and mild steel can be considered for use with most liquid metal coolants. The principal liquid metals concerned in possible reactor designs are sodium, sodium-potassium alloys, lead, bismuth and lead-bismuth eutectic. Lithium, although attractive in many respects, is excluded because it has a high-capture cross-section for thermal neutrons, particularly the isotope Li^6, and a moderating effect on fast neutrons which probably rules it out for fast reactors also. The high neutron-capture cross-section of mercury limits its use to fast reactors. This emphasizes the need for the liquid metal to have a low neutron-absorption cross-section.

In addition, liquid metal should not acquire a high level of induced radioactivity which is intense and penetrating. Sodium is the best liquid metal compromising on the grounds of physical properties and compatibility, but it does acquire hard gamma radioactivity in reactor service and this necessitates heavy shielding. The only liquid metals worth considering which would not require such shielding are bismuth, lead and potassium, and even potassium becomes slightly gamma active.

No liquid metal can be used in a reactor until a satisfactory container is found; failure in a liquid metal circuit is normally a very serious matter. Apart from both chemical and thermal burning, fires and explosions are possible. A hydrogen explosion is possible when alkali metals react with moisture although dry steam does not react in this way. Another precaution taken in containment systems is allowance for expansion of liquid metal or during melting of the coolant from cold. Some of the important properties of liquid metals for reactor use are given in table 22.

Compatibility

Having selected possible liquid metals and containment materials for reactor use, compatibility of various combinations becomes extremely important. There are several difficulties which may arise through a reaction between liquid metal and a container, including liquid metal corrosion by penetration, solution or oxidation from impurities carried by the liquid metal, mass transfer and plugging. A great deal of compatibility work has been carried out with a view to finding satisfactory combinations. Where material is removed from the container by the liquid metal in a fairly uniform manner, the depth of material removed should be as little as 0·001 in./year or less for long term use. Additionally, the conditions of service have to be considered, particularly the effect of dynamic compared with static conditions.

Solution of the container in the liquid metal is the first obvious difficulty. The solubility of solid metal in another liquid metal at a given temperature can be predicted to a limited extent from fundamental properties. Generally speaking, a liquid metal will dissolve a low-melting point solid metal more easily than a high-melting point metal; a low heat of fusion of the solid would assist solution as would a large heat of mixing of the previously solid metal with the liquid, and the higher the temperature of the liquid metal the higher the solubility. More exact data is available from the equilibrium constitution diagrams of the solid/liquid systems concerned. Even more valuable data is gained from corrosion tests which simulate reactor conditions as closely as possible.

The dissolving of the solid may not be uniform. Intergranular components of a system may be preferentially dissolved by liquid metals. Alternatively, an element in solid solution may diffuse to the solid/liquid metal interface and undergo selective dissolution. Both of these mechanisms are illustrated by the action of molten lead on steel. Intergranular carbides are decomposed with the carbon dissolving in the lead and at the same time carbon may diffuse through the ferrite into the lead. Selective removal of alloy components which act as grain growth inhibitors is possible, in which case grain growth may occur to the possible detriment of the physical properties of the solid metal. Nickel is much more soluble in mercury than is pure iron and the nickel appears to be selectively dissolved from alloys containing nickel; stainless steels for example. A similar condition exists between nickel and bismuth (see table 23).

TABLE 23 *Solubility of some metals in bismuth at 500°C.*

Ni	0·04–0·05 w./o.
Cr	0·0075
Fe	<0·003
U	0·6

Liquid metals usually form compounds with the metals they attack rather than extensive solid solutions, and this may result in a diffusion barrier if the reaction layer is continuous. On the other hand, normally protective layers may be destroyed by liquid metals. For instance, some liquid metals or wetting agents dissolved in them such as magnesium, can reduce oxide layers on many solid metals. If the oxide layer was previously protective, the metal is then opened to attack. Furthermore, when the oxidized surface is reduced it is very effectively cleaned and diffusion welding tends to take place between the cleaned surface and metals in contact with it. This problem became particularly acute in some types of liquid-metal pump where bearings in contact with the liquid metal seized up.

Oxidation of container materials or similar attacks by impurities carried by liquid metals is another important problem. For instance, metals corroded by liquid sodium or sodium/potassium alloy may either gain or lose weight. A weight loss is usually associated with solution of the metal itself or of some minor constituent of the material

TABLE 22 *Some properties of liquid metals* *Eutectic

	Na	Na/K*	Hg	Bi	Pb	Li	Bi/Pb*
Thermal condy. .. c.g.s.	0·15	0·05	0·02	0·04	0·05	0·07	0·04
Sp. heat .. cals./gm.	0·30	0·21	0·032	0·03	0·03	1·09	0·03
Density .. gm./cc.	0·854	0·7	12·0	9·91	11·3	0·49	10·5
Viscosity centipoise	0·269	0·15	1·0	1·3	—	0·4	1·1
Resistivity μ ohm/cm. (300°C.)	19	78	125	130	92	50	120
Neutron c./s. barns	0·49	1·3	360	0·032	0·17	67	0·17
M. pt... .. .. °C.	97·8	−12·5	−38·9	271	329	179	124
B. pt. .. .. .. °C.	883	—	357	1,477	1,737	1,317	—

in the liquid sodium. A weight gain can usually be traced to a reaction in the system. The reactions are most often due to small amounts of alkali metal oxides in the molten alkali metals. Oxygen contents of the order of 0·001–0·01% are extremely important in this respect. Under such conditions, stainless steel gains weight due to the formation of a chromic oxide scale. The liquid coolant containing oxygen can decarburize a low-carbon steel and then proceed to dissolve slowly the ferrite.

High-purity uranium is attacked by the oxygen impurity in liquid sodium at temperatures up to 600° C. with the formation of uranium dioxide, the rate of oxidation being dependent on the amount of oxygen in the coolant. The oxides of beryllium, thorium, magnesium, aluminium, zirconium, vanadium and niobium among possible reactor metals in addition to uranium, are all more stable than sodium oxide. Sodium oxide in a liquid metal in contact with any of the above metals will therefore tend to be decomposed by them, with the simultaneous formation of the oxide of the reducing metal. To prevent this class of reactions the oxygen content of the liquid metal must be kept as low as possible and this process is described later. Impurities other than oxygen may initiate a similar class of reactions. Nitrogen, for instance, may be transferred from or through the liquid metal to form nitrides with the containment material.

Mass-transfer effects

The problem of mass transfer has been mentioned briefly in the section dealing with liquid fuels. In a liquid-metal cooled reactor, temperature differences in the coolant circuit are inevitable. If there is any solubility of the constructional materials in the liquid metal they will dissolve to the greatest extent in the high-temperature part of the circuit and tend to precipitate in the cooler part of the circuit. The coolant is then relatively unsaturated when it returns to the high-temperature zone and the process continues. Where dissolution is taking place the liquid metal generally attacks the container in an irregular manner, by pitting or intergranular penetration. In the latter case, whole grains may be undercut and dislodged.

Where the precipitation is taking place the process often starts by attachment of the precipitant to the wall of the container. This may build up sufficiently to block or 'plug' the circuit with disastrous results. Occasionally the precipitate may be carried in dispersion around the circuit. The solubility of solid metal in the liquid may be very small but if it precipitates in the cooler part of the circuit extensive mass transfer can still take place. The solubility of carbon in sodium/potassium is very small but carbon can be transferred easily from a high to a low carbon steel, particularly a stainless steel, in contact with the liquid metal. The transition state for the carbon in the liquid metal may be as a carbide, probably insoluble, or as free carbon.

The influence of impurities is again important in mass-transfer mechanisms. Mass transfer between ferrous constructional materials and a sodium coolant circuit is accelerated if the oxygen content exceeds 30 p.p.m. by weight. With very pure sodium, mass transfer is practically eliminated. It has been suggested* that at temperatures over 300° C. the oxygen allows a mixed oxide to be formed, $2Na_2O.FeO$, and that this is unstable at lower temperatures, releasing the oxygen for further attack.

On the other hand, the presence of oxygen in liquid metal can be beneficial as when present in lead-base alloys in controlled amounts. Here it will form or maintain protective oxide films on stainless steels. Mass transfer due to solubility changes can be avoided by encouraging stable compound formation. For instance, with uranium/bismuth liquid fuel, a zirconium addition inhibits mass transfer by the formation of zirconium nitride on the surface of the steel structural components. The steel usually provides a sufficient source of nitrogen.

Inhibition of liquid metal attack

Apart from avoiding obviously incompatible systems there are a number of methods which reduce the extent of liquid-metal attack. Probably the most far-reaching treatments are those which keep the oxygen content of liquid metals at as low a level as possible. Sodium at 400° C. with free access to oxygen will dissolve something like 0·05% by weight (500 p.p.m.), which would cause serious attack and mass-transfer problems. This level can be reduced by two processes, cold-trapping and gettering.

Cold trapping involves passing the contaminated liquid metal through a low-temperature zone where the oxygen solubility will be low, about 40 p.p.m. at 120° C. for instance, and filtering off the oxide which is precipitated. If, in addition, a metal whose oxide is more stable than sodium oxide is included in the circuit in a hot region, this will be oxidized at the expense of the sodium. The getter may be soluble in the coolant but the resultant oxide will normally be insoluble and may require continuous filtering. Magnesium and calcium dissolve in liquid sodium and act as soluble getters. Zirconium is insoluble in sodium but forms an oxide more stable than sodium oxide. It may be used as a solid getter in the form of a large surface area material such as swarf.

Both cold trapping and gettering become almost useless if there is an almost unlimited source of

*G. W. Horsley, *J. Iron St. Inst.*, 1956, **182**, (1), 43.

oxygen in contact with the liquid metal. Leaks must obviously be avoided as must the inclusion of any unstable scale either with the coolant or on the containment system. Cold trapping and gettering may reduce the concentration of impurities other than oxygen. Hydrogen and nitrogen can be cold-trapped and zirconium and calcium getter nitrogen, for instance. Magnesium and zirconium added to bismuth limit mass-transfer from steel containers. Magnesium getters oxygen from the liquid metal and the inner surface of the container. It has been shown that the zirconium is then absorbed on the steel forming there both an iron-zirconium compound and zirconium nitride as a self-healing protective film.

Protective films are sometimes effective in preventing liquid-metal attack and mass transfer. Although it is difficult to prevent mercury leaching nickel from nickel containing steels it is possible to limit the attack of mercury on nickel-free steels by adding 1–10 p.p.m. of titanium or zirconium to the mercury. An iron-zirconium or iron-titanium compound protective film is created on the steel. Damage to nickel-containing stainless steels by lead-bismuth eutectic at 500–600°C. due to leaching of nickel may be minimized by additions of nickel, calcium, or barium to the eutectic†. It is easiest to add nickel, and 0·6% in the eutectic acts as an effective inhibitor.

If the surface in contact with the liquid metal has an inert coating, this will be protective so long as it is continuous. A coating which is not continuous must be capable of self-healing or ultimately failure will occur although failure may be delayed in comparison with an entirely unprotected surface. If the protective oxide film on stainless steel is damaged the stainless steel will be attacked by liquid metals such as lead and bismuth systems unless the film is healed. It requires oxygen to do this and a system which is well gettered would not in this case allow the healing to take place and attack would be accelerated.

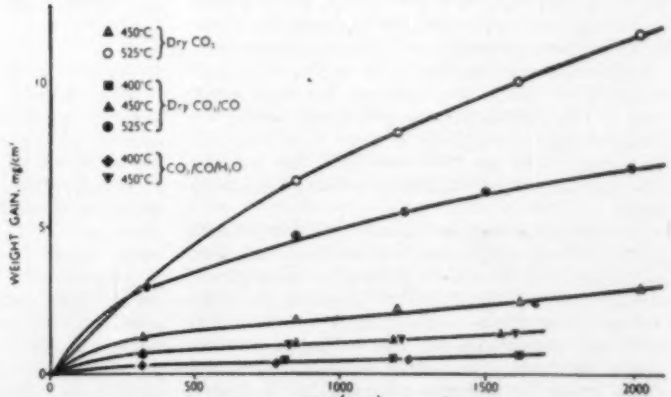
The degree to which the liquid metals wet the container system is an important consideration and the degree of wettability of a surface is profoundly affected by the cleanliness of that surface, particularly with respect to any oxide film present. It is generally thought that improved wetting between a liquid metal and a fuel element container or heat-exchanger surface improves the heat transfer characteristics. Wetting agents are sometimes added to liquid metals to improve heat transfer. Magnesium and calcium are added to mercury for this purpose and magnesium, with traces of zirconium and titanium, to lead-bismuth eutectic. The mechanism of the action of wetting agents in liquid metals is not entirely clear but reduction of oxides on container inner walls is a most important aspect of the mechanism.

Wetting may in other cases result in intergranular attack, frequently due to preferential solution of grain-boundary constituents. When possible, grain-boundary constituents should be dispersed by an appropriate heat-treatment process or preferably prevented during the original production of the component.

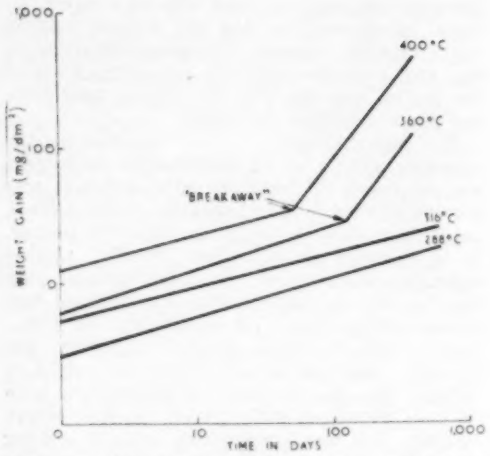
Coolant-gas problems

For a large proportion of reactors under development at present, high-purity CO_2 gas is specified as the coolant. Although the CO_2, when admitted initially to the reactor, is very pure, its composition in operation may alter due to a variety of reactions. In contact with graphite or various metals such as iron or magnesium, the CO_2 might be reduced to

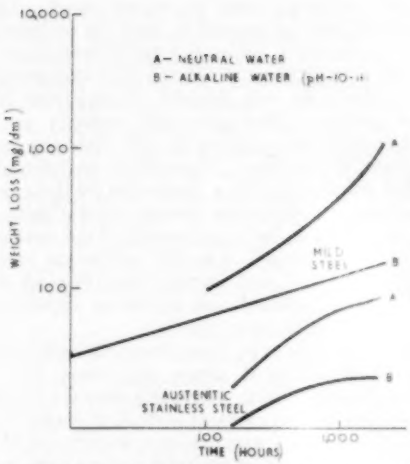
†L. I. Tsuprun and M. I. Tarytina, Int. Conf. on Peaceful Uses of Atomic Energy, 1955, paper 638.



42 *Oxidation of a silicon-killed boiler plate to B.S. 1501-154 in CO_2, CO_2/CO, and CO_2/CO/0·06% H_2O, in the range 400–525°C. at a pressure of 200 lb./sq. in. gauge*



43 *Example of breakaway corrosion occurring in Zircaloy 2*



44 *Corrosion of mild and stainless steels in neutral and alkaline water ('Nuclear reactor materials,' Frost and Waldren, Temple Press)*

some extent to CO. Moisture in the gas may lead to the water-gas type of reaction and hydrogen would be released and again hydrogen might result from the action of moisture on reactor metals. Several of these reactions cause corrosion themselves, but the modification of the coolant may lead to subsidiary corrosion.

Corrosion of steel in gas-cooled reactors

It is essential that the structural steelwork of a reactor should not undergo extensive corrosion or the load-bearing cross-section will be dangerously reduced. It is also necessary that any scale formed should be as adherent as possible so that it is not carried by the gas stream into the reactor core where it can become activated.

Because of the uncertainty of theoretical treatments of oxidation of steels in CO_2 under reactor conditions and the difficulty inherent in extrapolating the short-term results of complex systems, considerable experimental work on the behaviour of steels in reactor environments has been necessary. This has confirmed theoretical predictions that the rate of oxidation of steels is substantially independent of gas flow rate and that pressure changes do not have a marked effect on oxidation rates.

In the early stages at least the oxidation of mild and low-alloy steels follows a parabolic rate form indicating that the scale is protective. Examples of this are given in fig. 42. The curves can be represented by equations of the form $W^n = kt$, where W is the weight gain per unit surface area; t, the time; and k, the reaction rate constant. The value for n varies for different materials but in general lies between 2 and 3. It has also been established that k increases logarithmically with temperature so that $\log k = C/T$ where C is another constant and T is the absolute temperature.

From this relationship it is possible to predict k at various temperatures from a limited number of tests. In spite of this, it is not always possible to predict long-term corrosion results from short-term tests. The above equations are dependent on a protective type of oxide film and do not allow for film cracking or changes in the oxidation mechanism.

The presence of CO in the gas appears to have little effect on oxidation rates in steel and any slight effect which does exist is beneficial (fig. 42). Small amounts of carbon and iron carbide have been detected in the oxide film, which suggests that the normal reaction for steel in CO_2

$$3Fe + 4CO_2 \rightarrow Fe_3O_4 + 4CO$$

is slightly oversimplified.

When a small concentration of water vapour is present in addition to CO_2, the early reaction rate appears unaffected but breakaway can occur, as shown in fig. 43.

In all corrosion problems in a reactor, the influence of irradiation has to be considered. Oxide films on metals are ionic in character and are sometimes sensitive to radiation, and additionally there is the possibility of abnormal phase changes and of transmutation effects changing the chemistry of the reaction. Hittman and Kuhl have shown aluminium to be attacked less in the presence of irradiation, but copper and mild steel much more. They concluded that where corrosion resistance depends on the formation of a protective oxide film, the irra-

diation tends to act like an active oxidizing agent and so tends to inhibit corrosion, but where there is no protective oxide film, radiation increases the corrosion rate.

High-temperature water systems

Any water used in a reactor will be very pure at the start having been circulated through ion-exchange resins for the purpose of demineralization, but slight corrosion of reactor or heat exchanger components is inevitable and the water will carry at least small amounts of corrosion products. These corrosion products may become activated in the reactor core and require removal. This can be done by circulating part of the cooling water over ion exchange resin. A further problem arises from the effects of irradiation on the composition of water itself. Neutron irradiation alters the equilibrium ionization of water in favour of more ions and these in turn may be converted to molecular oxygen and hydrogen thus:—

$$4H_2O \rightleftharpoons 4H + 4OH$$

$$4H + 4OH \rightarrow 2H_2 + 2H_2O + O_2$$

This reaction may be prevented by adding hydrogen to the water. In the presence of γ-radiation the reverse process applies and $2H_2 + O_2 \rightarrow 2H_2O$. This reaction tends to counterbalance the first. When nitrogen is present this may also enter the reaction thus:—

$$N_2 + 3H_2 + 2H_2O \rightarrow 2NH_4OH$$

$$2N_2 + 5O_2 + 2H_2O \rightarrow 4HNO_3$$

The formation of ammonia will tend to reduce corrosion of ferrous parts and to this extent is beneficial. The formation of nitric acid is not common but it has been noticed and has been responsible for increased corrosion damage.

Containment of pressurized high temperature water systems for reactor purposes is normally in mild steel or stainless steel. Both form protective magnetite type oxide films in pure de-aerated water and have acceptably low corrosion rates. The corrosion rate of the mild steel is considerably higher than that for stainless but may be lowered by making the water alkaline (pH 10), fig. 44. The use of mild steel, because of the increased amount of corrosion product debris to be removed, throws a heavier load on the water purification system.

Pressure vessels

In the construction of pressure vessels for reactors, particularly gas-cooled reactors, there are three major aspects to be considered. The vessel should have a high resistance to creep deformation at its operating temperature; it should resist failure by brittle fracture and should be weldable largely 'on site' in relatively heavy sections. The thickness of plate used for gas-cooled reactor shells is 2 to 4 in. and the completed vessels are large, 50 to 70 ft. dia. The Calder Hall pressure shells were the largest vessels in such plate thicknesses when they were assembled.

It is known that brittle failures are more common in large vessels, thick plates and welded structures, particularly when welding takes place under site conditions. Also the effect of irradiation is to raise the ductile/brittle transition temperature, so all these effects combine in making the transition temperature a very important consideration. Even if a steel vessel spent long periods below its transition temperature, brittle fracture is not inevitable. The fracture has to be initiated by a high stress, usually localized by a notch or a crack, a defect in the plate or the weld, a sharp change in cross-section or undercutting in welding.

In reactor-vessel construction a determined effort is made to overcome all of the contributory factors to brittle failure although theoretically removal of only one of the main factors should be effective. Thus, notches are eliminated by good design, good welding and adequate inspection; high local stresses are avoided, particularly by stress-relieving the complete structure, and the structure is also maintained above its transition temperature throughout its life.

Extensive developments have been made to produce radiographically sound welds between heavy plates in the open, paying particular attention to the notch ductility of the weld and the neighbouring heat-affected zone irrespective of the position of the weld. As a result, it is now possible to specify welding conditions such that notch ductility of the weld is no longer a serious problem and its mechanical properties compare well with those of the plate.

Internal stresses in the completed structure are reduced by a stress-relieving treatment. An electric-heating grid is built inside the shell and is fed with a heavy current, while the outside of the shell is lagged as it is in service. The whole structure rises slowly to a satisfactory relieving temperature and is then allowed to cool slowly.

A relatively low transition temperature, about –35°C., can be attained in a pressure-vessel steel with a fine grain size and a minimum of inclusions. The pressure vessel then starts its working life in the unirradiated condition at a temperature which will exceed the transition temperature by a good margin. The temperature of the shell is likely to be safely in excess of the transition point as long as the reactor is working. In fact, the working temperature may be such as to concern the creep resistance of the steel rather more than the transition temperature. Generally speaking, the pro-

continued on page 210

Automatic solvent degreasing plant

concluded from page 200

removed and the next batch of soiled parts is loaded, and the cycle of loading and unloading operations continues, each time indexing the parts a further stage through the cleaning process. The process time is under the control of a time clock and the operator cannot advance the conveyor until the timed period is completed.

Treatment. The carriers first enter the vapour zone where degreasing commences as the vapour condenses on the parts. They then move into the first immersion tank where the brisk boiling action and degreasing power of the solvent removes the grease, oils and solids suspended in them. They then emerge from the liquid into the heavy vapour where the cleaning and degreasing action continues and then enter the second immersion tank of clean boiling-solvent, which is constantly restored by pure solvent flowing from the condensing coil.

Continuous distillation system

The in-built distillation system ensures the maximum possible recovery of vaporized solvent and by a system of overflows, it weirs surface dirt and sludge from the immersion tanks into a still tank. The rising vapour from the boiling solvent comes into contact with the condensing coil which converts it into liquid solvent. This falls into a trough and is returned through a water separator to the second immersion tank thus constantly replenishing the solvent already there. From there the solvent weirs over to the first immersion tank and the surface oil and scum on that tank flows into the still. The soilage collects in the still for easy removal at cleaning-down times through the cleanout doors, and the actual operating tanks are kept free of excessive soiling.

The copper condensing coil and water jacket through which cold water is continually circulating provides a complete cold strata which condenses the vapour and allows none to escape to atmosphere. If for any reason, such as a failure in the water supply to the condensing system, the vapour should tend to rise above the desired level, a thermostat is fitted which will automatically switch off the heating supply in the immersion and still tanks. An additional safety feature is a thermostat fitted in the water out-flow from the condensing coil; if the temperature of that water rises above the level for effective condensation of the vapour, then the thermostat operates a circuit which automatically increases the flow of water through the condensing coil system.

These safety provisions which ensure that vapour does not escape to the atmosphere both protect personnel from the possible toxic effects of the fumes and ensure that there is a minimum loss of solvent.

In addition to the vapour and water-flow thermostats, low-level thermostats are fitted in the two immersion tanks and in the still tank. The purpose of these is to cut off the heating medium if the solvent should rise above 248°F. (owing to accumulation of oil). Heating above this temperature would ultimately decompose some of the solvent, and the acid thus formed would attack the plant.

Construction can be in stainless steel, or galvanized mild steel according to requirements. Dawson Bros. Ltd. state, however, that they prefer to supply the conveyor chain in stainless steel, but that if required, alternative materials can be supplied.

Automatic dip-type solvent degreasing plant

This machine is suitable for small-scale applications where the requirements are for flow-line production. It is available as a vapour machine or as an immersion/vapour machine.

The operator pushes the work to be cleaned on to a pneumatically operated platform and presses a starter button. This lowers the platform down into position in the treatment zone where it remains for a fixed period predetermined by an automatic timer. The solvent (either vapour or immersion vapour according to the machine) dissolves the grease and oil which fall to the bottom of the tank. At the end of the cleaning period the platform is automatically raised out of the treatment zone, to the unloading position. The upward speed of the platform is fixed at a safety level to eliminate the possibility of vapour being brought out of the machine. The operator pushes the next batch of soiled parts on to the platform thus discharging the clean parts on to a roller track at the other side.

A cold strata above which the solvent vapour cannot pass is created by a condensing coil, and a water jacket connected to a common cold water supply. The vapour condenses on the coils to form pure solvent which falls into a trough and returns through a pipeline to the boiling solvent at the bottom of the tank.

Metallurgy in nuclear power technology

concluded from page 209

cedures used in producing fine-grained notch ductile steels result in poorer creep strength so an adequate compromise must be made between notch ductility and creep strength while not sacrificing weldability.

An alternative method is to build a double shell where the outer layer is made from a steel with a low transition temperature and the inner layer in contact with the hot gas, at 400°C. or more, chosen for its creep resistance. On the double shell system, for higher gas temperatures, an alloy or stainless steel could be used for the thin inner shell but on a single shell the problems of producing and welding sufficiently thick alloy steel plate would be extremely difficult.

Manufacture of Birlec furnaces in Australia

An agreement has been made between AEI-Birlec Ltd. and Major Electric Furnaces Pty. Ltd. Melbourne, Australia, for the setting up in Melbourne of a new company to be known as Birlec-Major Pty. Ltd. Offices of Birlec-Major Pty. Ltd. will be situated in Chesterville Road, Moorabbin, Melbourne.

Birlec-Major Pty. Ltd. will manufacture every type of electric- and gas-fired furnace, for heat treatment and melting processes, at present built by Birlec and their associate companies in the U.K. In addition to serving the Australian market, the new company intend to market their products in New Zealand and South-east Asia.

Since 1952 Birlec furnaces have been manufactured under licence by Major Electric Furnaces Pty. Ltd., and are installed in most Australian industries. This agreement now terminates with the formation of the new company.

Electrical Aids in Industry *Data Sheet* **No. 16**

Speed control of Electric Motors

'Variable' speed may involve two or three (or more) speed steps or infinitely variable (stepless) speed control. It is this latter type which is considered below. Of the many advantages of electric drives, the opportunity offered for infinitely variable speed control is outstanding. Unfortunately this advantage is not used as much as it might be.

Principal Factors Affecting Choice of Drive

(a) First cost, (b) Efficiency, (c) Speed range, (d) Regulation, (e) Power-to-weight ratio, (f) Availability of supply, (g) Maintenance and reliability, (h) Change in power and torque over the speed range, (i) Simplicity of control gear, (j) Effect of variation in supply, (k) Power factor, (l) Characteristics of the load, (m) Operational environment, (n) Braking requirements.

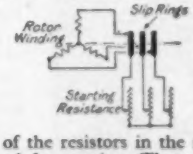
The following are some methods of obtaining infinitely variable speeds:

Alternating Current Motors

The vast majority of electric drives employ A.C. motors. Although not quite so flexible as D.C. motors, there are available many types which give a large measure of speed variation.

INDUCTION MOTORS. Although the squirrel-cage motor is essentially a constant-speed machine, it is much used for stepless variable-speed drives with one of the following types: (a) Eddy-current coupling, (b) Ferromagnetic particle coupling, (c) Mechanical drives, e.g., belt drives and friction drives, (d) Hydraulic variable-speed drives.

SLIP-RING MOTORS. The slip-ring motor, which costs more than the squirrel-cage motor, can be varied in speed by



means of the resistors in the rotor circuit used for starting. The amount of resistance in circuit can be varied by hand, push-button or automatically controlled contactors.

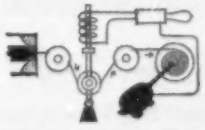
A.C. COMMUTATOR MOTORS. These are three-phase induction motors provided with additional windings which, through a commutator and brushes, permit speed adjustment in either direction below and above synchronous speed. The brush gear can be automatically controlled in such a way as to vary the speed in accordance with a known programme or cycle of operation.

Ward-Leonard System

In this system the armature of a D.C. motor is supplied at variable voltage from a separate generator. The generator may be driven by an A.C. or D.C. motor directly coupled to it and to an exciter which supplies the field windings of the generator and main motor. By means of a potentiometer resistance, the generator voltage may be varied from maximum to zero.

Electronic Motor Control

The speed of motors can be controlled accurately by electronic methods. Such drives can respond in any desired manner to variations, and several drives



can be interlocked so that their speeds are always in the same ratio. The system can be speeded up or slowed down from a 'master' controller, but for 'running in' purposes the speed of each drive can be individually regulated. Electronic speed control has been successfully applied where human control is not possible, e.g., in register control. In this example, print must always be placed at exact position on packaging material.

Direct Current Motors

The striking advantages of D.C. motors sometimes make it worth while installing a motor-generator set, a mercury-arc or semi-conductor rectifier. The speed of D.C. motors is easily controlled by inserting a resistance in series with the motor. Although this can result in a certain amount of wasted electricity, the benefits derived will often heavily outweigh such losses.

For further information get in touch with your Electricity Board or write direct to the Electrical Development Association, 2 Savoy Hill, London, W.C.2. Telephone: TEMple Bar 9434.

Excellent reference books on electricity and productivity (8/6 each, or 9/- post free) are available—'Electric Motors and Controls' is an example.

E.D.A. also have available on free loan in the United Kingdom a series of films on the industrial uses of electricity. Ask for a catalogue.

7916/4

CUT HERE

NEWS

New nuclear engineering company formed

Three well-known industrial concerns, Imperial Chemical Industries Ltd. (Metals Division), Rolls-Royce Ltd., and the Rio Tinto Co. Ltd., have jointly formed a new company to operate in the field of civil nuclear engineering in collaboration with the atomic power consortia. The new company is to be called Nuclear Developments Ltd., and the United Kingdom Atomic Energy Authority has been kept fully informed of its formation.

Each of the participants has, in addition to wide technical resources and skills, experience which will be appropriate to the future rôle of the new company in nuclear engineering. Rio Tinto mines, extracts and processes uranium on a large scale. Rolls-Royce has been engaged in the nuclear field for the past eight years and has a specific interest in marine nuclear propulsion. I.C.I. Metals Division has made several notable contributions to technological progress in nuclear engineering over the last 20 years and has exceptional facilities for the manufacture of nuclear metals and reactor components.

English Electric-Delapena induction heating agreement

Servicing of English Electric radio-frequency induction heaters will be taken over by Delapena & Son Ltd., Cheltenham, as from June 1, 1961. This follows the cessation by English Electric of activity in the R.F. heating field.

Continuity of servicing, maintenance and supply of spare parts to all present users of English Electric induction heating equipment is assured by this arrangement with Delapena, who are specialist engineers in induction heating. Delapena already has a service department whose sole concern is the installation and maintenance of induction heating equipment; this department is being considerably expanded to cope with the additional work and service engineers are being given courses of instruction in the maintenance of English Electric equipment. Adequate stocks of spares will be made available and from June 1 will be obtainable from Delapena's service department. Until this date spares will continue to be held at the English Electric Company's Kidsgrove Works.

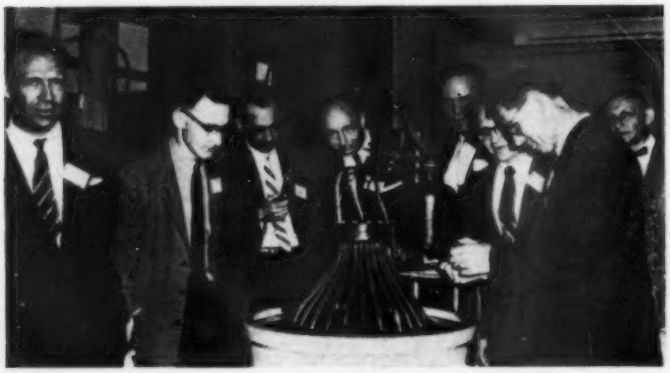
Heavy-duty gear wheel centres cut by oxy-propane

Two large gear blanks, probably the largest ever fabricated in single pieces, have been made at the St. Andrew's Road Works of David Brown Industries Ltd., Huddersfield. The finished gears weigh 25 tons and are 13 ft. 6 in. o.d. by 3 ft. overall width. They will be used in the tilting mechanisms of Bessemer steel converters.

The centre boss for each gear weighs 12 tons and is 5 ft. dia. by 3 ft. wide. The first manufacturing operation consisted of flame cutting a 31-in. dia. bore in the boss. This was done in a single cut using a British Oxygen 55-in. Universal Cutting Machine fitted with a P.N.M. 60 heavy-duty cutter and a ½-in. nozzle mixing propane nozzle.

Using B.O.C. cylinder propane and oxygen at a pressure of 25 lb./sq. in., the cut involved 8 ft. of travel around the bore circumference, at a depth of 3 ft. It was completed in 40 min. with less than ⅛ of an inch taper over the full depth.

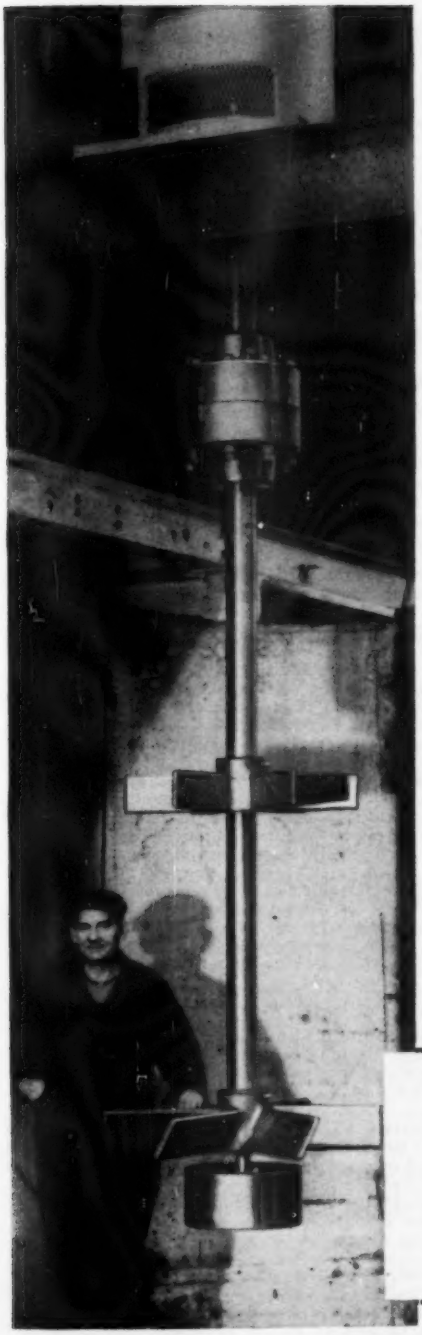
Picture shows the wheel centre being examined after the cutting operation.



World corrosion experts visit British laboratories

Sixty experts on fighting metallic corrosion from all over the world, in London this week for the first international conference on the subject, visited the laboratories of the British Non-Ferrous Metals Research Association in Euston Street, London, to see the progress being made by Britain in this field.

In the photograph a party which includes the well-known U.S. corrosion chemist, Prof. H. H. Uhlig (fourth from left), is seen examining a test rig simulating conditions which arise in sea-water condensers or heat exchangers when the cooling water is driven through at high speed, creating considerable corrosion.



Agitator shaft

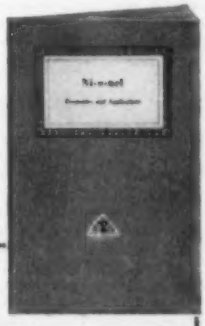
for rugged service in

Ni-o-nel*

NICKEL-CHROMIUM-IRON ALLOY

In this heavy-duty turbo-type agitator for benzole washing, designed and built by L. A. Mitchell Limited, the shaft is of corrosion-resistant Ni-o-nel, a new Wiggin nickel-chromium-iron alloy with copper and molybdenum additions. Developed especially to meet corrosive conditions of unusual severity, Ni-o-nel is highly resistant to hot acids and oxidizing chemicals and has remarkable resistance to pitting and stress-corrosion cracking. It is fast becoming established as an ideal material for many applications involving problems of severe corrosion.

Test data, fabrication details and typical uses, together with physical and mechanical properties of Ni-o-nel, are given in this Wiggin publication.



SEND FOR YOUR COPY TO-DAY

To: HENRY WIGGIN & COMPANY LIMITED
Wiggin Street, Birmingham, 16
Please send me a copy of
your publication on "Ni-o-nel".

NAME _____

APPOINTMENT OR DEPARTMENT _____

COMPANY AND ADDRESS _____

MT/C26/5

*TRADE MARK

HENRY WIGGIN & COMPANY LIMITED • WIGGIN STREET • BIRMINGHAM 16

TGA C34A

PEOPLE

THE MINISTER FOR SCIENCE, Lord Hailsham, has appointed **Sir Harold Roxbee Cox** as chairman of the Council for Scientific and Industrial Research for five years from October 1, 1961. He will succeed Sir Harry Jephcott, who has been chairman of the Council since its formation in 1956. Sir Harold has been a member of the Council since 1957.

Sir Harold Roxbee COX, D.SC., PH.D., D.I.C., M.I.MECH.E., F.R.AE.S., F.INST.F., F.I.AE.S., who is 58, is an engineer by profession and has spent over 20 years in the government service. In this time he has done pioneer work on jet propulsion, gas turbines and problems of fuel and power. After six years as Chief Scientist of the Ministry of Fuel and Power, he left government service in 1954 for industry, and in January of this year was appointed chairman of the Metal Box Company Ltd. He is active in the field of higher technological education and is chairman of the National Council for Technological Awards.

Prof. W. R. D. Jones will retire from the chair of metallurgy and fuel technology at the University College of South Wales and Monmouthshire, Cardiff, at the end of the present academic session. He graduated from that College in 1919, and in the same year commenced teaching duties. Coming from a family well known in mining circles, and forming a close association with the iron and steel industry in South Wales, his research work has nevertheless largely been directed towards light alloys containing magnesium. His determination of the copper-magnesium phase-diagram brought him his D.Sc. in 1932, and in the following year he was appointed head of the Department in succession to Prof. A. A. Read. Prof. Jones has always taken a very full part in academic work, being at various times deputy principal, dean of the Faculty of Science and a member of the Academic Board of the University of Wales. Combined with this he promoted a vigorous research school, the publications of which are notable contributions to our knowledge of magnesium alloys. Other work has been concerned with strain-ageing of steels and the viscosity of molten metals and alloys.

Dr. H. K. M. Lloyd, who has been appointed to succeed Prof. W. R. D. Jones, is senior lecturer in metallurgy in the University of Nottingham. He graduated with honours in metallurgy at the University College of Swansea in 1942, and then gained industrial experience as a metallurgist in a steelworks, and afterwards became experimental officer in the Aeronautical Inspection Directorate. As a result of research on hydrogen in steel in the University of Sheffield he was awarded a Ph.D. in 1948 and the Brunton Medal, and continued for a year on the teaching staff. Since 1949 Dr. Lloyd has lectured at the University of Nottingham, first in the Mechanical Engineering Department, and from 1954 in the new Department of Metallurgy, which he largely established and equipped. He has maintained close contacts with the iron and steel industry and various engineering firms, which have sponsored some of his research work. This has chiefly been concerned with engineering metallurgy, and his work has been published in a variety of journals. In 1950 Dr. Lloyd was invited to examine metallurgical problems in an oil installation in the Persian Gulf, and during 1951 was awarded a Nuffield travelling fellowship and visited plants in the United States and Canada. His interests have extended to technical institutions and he is a governor of Corby Technical College, while as a founder member of the East Midlands Metallurgical Society he became president in 1953.

Mr. B. J. Harpham, of Collingwood Conveyor Equipment Ltd., Collingwood Iron Works, 18–22 Northdown Street, London, N.1, has been appointed managing director.

Mr. Ernest E. Thum, editor-in-chief of *Metal Progress*, died on April 10. Well known on both sides of the Atlantic, Mr. Thum started and built up *Metal Progress* on behalf of the American Society of Metals.

Mr. A. R. Robertson has been appointed registrar of the United Steel Companies Ltd.

Mr. E. L. Morgan, formerly works metallurgist, has been appointed chief metallurgist of Workington Iron and Steel Co., a branch of the United Steel Companies Ltd. **Mr. A. G. Hock,** formerly research manager, has been appointed metallurgical consultant at Workington.

Mr. J. C. McVeigh, M.A., M.SC., A.M.I.MECH.E., has been appointed principal lecturer in the Department of Mechanical Engineering, Borough Polytechnic, London.

Mr. G. C. Richardson has been appointed export manager, Overseas Division, the British Oxygen Co. Ltd. This is a new appointment and has been made to strengthen B.O.C.'s overseas sales activities. Previously Mr. Richardson was general sales manager, J. H. Carruthers & Co. Ltd., East Kilbride, Glasgow, manufacturers of pumps and cranes. Before that he was assistant sales manager, Langley Alloys Ltd., Slough.

During the war Mr. Richardson served as a Lieutenant in the Fleet Air Arm. After the war he went to Cambridge University and then joined the English Electric Co. Ltd. For three years he was seconded from the English Electric Co. Ltd. to the Public Schools Appointments Bureau.

Mr. H. G. Hinckley has been appointed manager of the Machine Tool Control Department of Ferranti Ltd., Edinburgh. He replaces **Mr. D. T. N. Williamson,** manager of the Department since its inception in 1952, who has left to become Director of Research and Development at Molins Machine Co. Ltd., in London.

Mr. W. E. Hughes has been appointed director and general manager of British Industrial Gases Ltd., Enfield. He succeeds Mr. F. Blackmore, who is now manager of Equipment Development, Technical Division, the British Oxygen Co. Ltd.

Sir Arthur Vere Harvey, C.B.E., M.P., has been appointed to the Board of CIBA Ltd., Basle. This is the first time that an executive of the CIBA Group of Companies in Great Britain has been made a director of the parent company and may be considered as an indication of the importance attached by the Swiss Board to the rôle of the British Companies in this international chemical group.

Sir Arthur joined CIBA in 1957 as chairman of its four British subsidiary companies, and was recently appointed managing director of the newly formed CIBA United Kingdom Ltd.

Classified Advertisements

FIFTEEN WORDS 7*s.* 6*d.* (minimum charge) and 4*d.* per word thereafter. Box number 2*s.* 6*d.* including postage of replies. Situations Wanted 2*d.* per word.

Replies addressed to Box Numbers are to be sent, clearly marked, to Metal Treatment and Drop Forging, John Adam House, John Adam Street, London, W.C.2.

SITUATIONS VACANT

SPECIALIST SALESMAN IS REQUIRED for an important machine tool company dealing in forging hammers and plant equipment.

Applicants must be practical engineers with a knowledge of forging practice and be willing to visit companies throughout the United Kingdom. A motor-car will be provided and usual out-of-pocket expenses.

This is a progressive position with a well-known company and an attractive pension scheme is in operation.

Please state details of experience and salary required to Box No. SS137, METAL TREATMENT AND DROP FORGING.

LANCHESTER COLLEGE OF TECHNOLOGY, COVENTRY

Principal: A. J. RICHMOND, B.SC.(ENG.), PH.D., M.I.MECH.E.

Appointment of Additional Academic Staff

Applications are invited for following post, duties to commence September 1, 1961, or from date to be arranged

Department of Chemistry, Metallurgy and Textiles

Head of Department: M. E. FOSS, B.SC., PH.D., F.R.I.C.

ONE LECTURER IN METALLURGY

mainly for Physical Metallurgy, to teach in H.N.C., A.I.M. and degree standard courses

Candidates should normally hold University degree or Diploma in Technology and a professional qualification. Applicants who do not meet these requirements may be eligible by virtue of outstanding experience or other qualities. Industrial experience is necessary, while some previous teaching or research experience would be an advantage.

The College is largely housed in new buildings occupied in 1960. The remaining buildings will be occupied during 1963. Equipment and general facilities in the new buildings are excellent and a real opportunity exists for the staff to take part in the many further educational developments which are projected in close and growing co-operation with industry. An outstanding feature of all Departments are many well-supported postgraduate courses of lectures. It is hoped that several Dip.Tech. courses will be offered from September, 1961.

All staff are encouraged to undertake research and/or consulting work.

Salary (now under review):

Lecturers, £1,370 × £35(4) × £40(1)—£1,550 p.a.

In certain circumstances a candidate may be paid a commencing salary above the minimum of the scale.

Further particulars and application forms from the Registrar, Lanchester College of Technology, Priory Street, Coventry, to whom applications should be submitted within 12 days of the appearance of this advertisement.

W. L. CHINN,
Director of Education

SITUATIONS VACANT cont:

FOREMAN REQUIRED for production department of North Midlands engineering works comprising Drop Stamping with some repetitive machining and assembly. Age preferably 35-40 years. Superannuation and profit-sharing schemes.—Box No. B721, c/o Walter Judd Ltd., 47 Gresham Street, E.C.2.

BOROUGH POLYTECHNIC

BOROUGH ROAD · LONDON · S.E.1

Principal: JAMES E. GARSIDE, M.SC.TECH., PH.D., F.R.I.C., F.I.M., F.INST.F.

The Governors invite applications for the following appointment:

Division of Metal Science

Head of Division: G. ISSERLIS, B.SC.(ENG.), A.I.M.

ASSISTANT LECTURER (GRADE B) IN METALLURGY

Applicants should be University Graduates in Metallurgy or hold an equivalent qualification. Industrial and/or research experience desirable. Experience in the fields of Corrosion and Protection of Metals with special reference to Metal Finishing would be an added qualification. Research encouraged and facilities made available.

Salary Scale: £700 p.a. by annual increments of £27 10s. to £1,150 p.a., plus allowances for training, qualifications and experience, together with the 'London Allowance' of £38 or £51 p.a. according to age. Candidates may be placed on the scale at a point appropriate to teaching and/or industrial experience.

Further particulars and Application Form obtainable on application to the undersigned

FREDK. J. PACKER,
Clerk to the Governing Body

PLANT WANTED

VERTICAL-TYPE ELECTRIC NITRIDING FURNACE. Retort usable dimensions 2–3 ft. dia. by 3–4 ft. long approximately. Temperature record/control, dissociation cubicle and atmosphere fan equipment desired. Lift-off bell-type furnace also considered. State furnace manufacturer, dimensions, age and price required. Write 2445, Wm. Porteous & Co., Glasgow.

MACHINERY FOR SALE

HEENAN & FROUDE OIL COOLING TOWER, complete unit, 4 ft. 6 in. x 4 ft. 6 in. by 9 ft. high.—Whitefield Machinery & Plant Ltd., 48 Chatham Street, Edgeley, Stockport.

DAWSON BROS. conveyor-type, combination washing and rinsing, steam-heated degreasing machine, complete in all detail. Condition, second-hand, unused. Whitefield Machinery & Plant Ltd., 48 Chatham Street, Edgeley, Stockport.

*NOW AVAILABLE FROM STOCK

All prepublication orders for the 1960/1 EDITION of

RYLAND'S DIRECTORY

have now been fulfilled, and copies can be supplied immediately from stock

May we suggest you place your order at once with

The Publisher,
Ryland's Directory,
17/19 John Adam St.,
London, W.C.2

Price
84/-
(Post free in the U.K.)

METAL CUTTING OILS
BROACHING OILS
GRINDING OILS
TAPPING OILS
HONING OILS
SOLUBLE OILS
(Emulsion types, Translucent types)
DRAWING OILS
HYDRAULIC OILS
(including Houghto-Safe fire-resistant types)
QUENCHING OILS
TEMPERING OILS
LUBRICATING OILS
AND GREASES

When it's a question of cutting oils and coolants . . . .

the obvious answer is to call in Edgar Vaughan—a specialist firm with over sixty years' experience in this field. The recommendation of suitable cutting oils and coolants is undertaken by an experienced staff who are fully equipped to give production engineers the benefit of an intensive research and technical service, without obligation.

Informative literature is available on request.

Edgar Vaughan & Co. LEGGE STREET, BIRMINGHAM, 4.

In association with the Houghton group of companies all over the world.

Works and depots at: Birmingham, London (Southall), Manchester, Liverpool, Bristol, Glasgow.

FLAME HARDENING

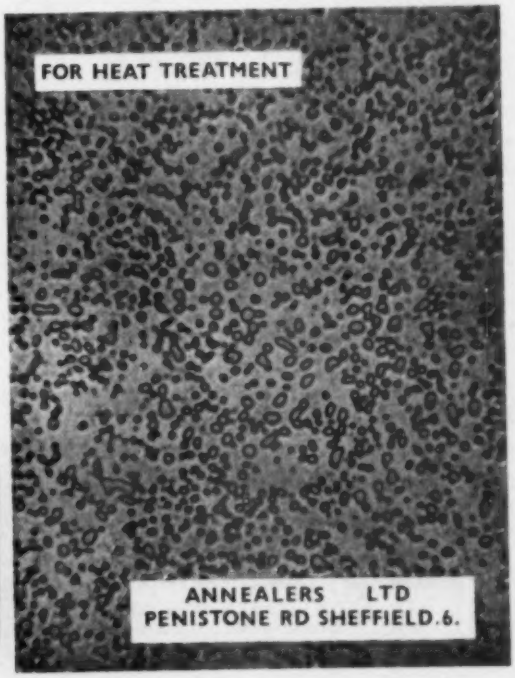
CASE HARDENING
CYANIDE HARDENING
HARDENING OF PRESS TOOLS AND DIES ETC.
PLASTIC AND RUBBER MOULDS
HEAT TREATMENT OF FORGINGS AND MACHINE PARTS
ANNEALING
NORMALISING
STRESS RELIEVING

HEAT TREATMENT SPECIALISTS by

ENGINEERING HEAT-TREATMENTS (Manchester) LTD.

TELEPHONE: TRAFFORD PARK 3114

CORNBROOK PARK RD., OLD TRAFFORD, MANCHESTER 15



tool life trebled!

Grad

COLLOIDAL GRAPHITE

GRAD, by constant research and exhaustive laboratory and field tests, are meeting the exacting demands of British industry by supplying colloidal graphite dispersions that in many instances can double overall production.
Another significant aspect of the enterprising services that GRAD provide for their customers, is delivery in half the normal time. If yours is a lubrication problem consult GRAD. They know what you may want to know about lubrication.

cleaner to use!

GRAPHOIDAL DEVELOPMENTS LTD

CONSULTING LUBRICATION ENGINEERS

WREAKES LANE, DRONFIELD, NEAR SHEFFIELD

ABBEY HEAT TREATMENTS LTD.

Plaza Works, High St., Merton, S.W.19

•

Specialized Heat Treatment in our NEW Capacity Furnace with non-oxidizing atmosphere

•

SPECIALLY DESIGNED for the heat treatment of high temperature alloy materials up to 1,300°C.

•

Enquiries will be dealt with personally by our Technical Staff · Ring CHERRYWOOD 2291/2

A.I.D. D.I.ARM. I.E.M.E. & A.R.B. Approved

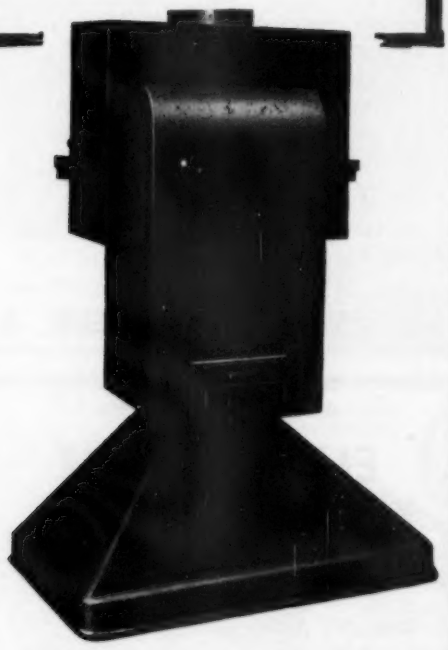
Cut your finishing costs on
DIE SINKING & FETTLING
By using the British made
BRIGGS-AJAX
Range of
AIR GRINDERS
which have achieved an enviable reputation for reliability since their introduction 21 yrs. ago.

AJAX JUNIOR, 100,000 r.p.m. for Stones $\frac{3}{32}$" to $\frac{1}{8}$" dia.
AJAX MK. III, 50,000 r.p.m. for Stones $\frac{1}{4}$" to $\frac{3}{4}$" dia.
BRIGGS MK. II, 28,000 r.p.m. for Stones $\frac{1}{2}$" to 1" dia. (deep reach)
BRIGGS MK. V, 10,000 r.p.m. for Stones $1\frac{1}{4}$" to 2" dia.

Literature on request from Manufacturers

BRIGGS BROS. (ENGINEERS) LTD.
206 EDWARD ROAD, BIRMINGHAM, 12
Telephone: CALthorpe 2995

Dust & Grit Collectors



This photograph shows an Alldays & Onions UF/1 Dust Collector, primarily for use with hearths and designed to meet the requirements of the Clean Air Act.

ALLDAYS & ONIONS LTD

GREAT WESTERN WORKS · BIRMINGHAM 11
Phone: VICtoria 2251-4

London Office: 2 Queen Anne's Gate, Westminster, London, S.W.1
Phone: Whitehall 1923/4/5

TWIN VORTEX

A NEW APPROACH TO INDUSTRIAL BURNER DESIGN

FOR EVEN FURNACE ATMOSPHERE

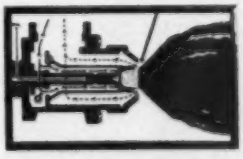
Reduces scaling

caused by INCORRECT furnace atmosphere

With most burners oil travels well into the furnace before combustion can take place. Air (counterblast) directed from the opposite side only results in an intense highly oxidizing ball of flame in the centre and two relatively cold areas at each side. The result is poor metal treatment and a considerable increase in the scaling of the metal.

Representing an entirely *new* approach to oil burner design, this new Premier TWIN VORTEX improves the efficiency of the furnace and of metal treatment process considerably, whilst effecting a simultaneous saving in oil consumption. TWIN VORTEX offers other advantages including:—

★ Constant air/oil ratio
★ Automation self-proportioning through a 5:1 range
★ Constant supply of atomizing air
★ Independent control of combustion air
★ Burner can be mounted at any angle
★ Can be used on any grade of oil
★ Suitable for all types of furnaces
★ Suitable for steam boiling working on semi-automatic
★ Smoke virtually eliminated



WRITE FOR LEAFLET
ASK FOR DEMONSTRATION

TWIN VORTEX OIL BURNER

With the TWIN VORTEX (British Patent No. 800191/823560) the provision of a separate oil atomizing chamber (A) and twin vortex cups means instant atomization, immediate combustion, greater heating uniformity and furnace efficiency, quite apart from impressive fuel saving. Literature on request.
Automatic Temperature Control can easily be arranged for all types of Furnaces.

PREMIER

OIL BURNERS

PREMIER OIL BURNERS · Eastbourne Street · Walsall · Staffs
Telephone: Walsall 22430/23055

Use
MELLOPAD
Anti-vibration material...

...for incorporation in the concrete foundations of power hammers, drop stamps, foundry jolters to reduce transmission of vibration.

Also for the isolation of precision machines from external disturbances.

The picture shows Mellopad laid in a pit preparatory to casting the concrete block for a precision grinder, capacity 24 ft. x 18" dia.

Write to us for particulars and recommendations.

Photograph by courtesy of Messrs. Marfleet & Weight Ltd. Melbourne, Australia.

MELLOWES & CO. LIMITED. SHEFFIELD. 3.

THOMAS ANDREWS
AND COMPANY LIMITED
High-Grade Steel Makers

"MONARCH" — HIGH SPEED STEELS; HOT & COLD DIE STEELS; TOOL HOLDER BITS

"HARDENITE" — CARBON & ALLOY TOOL STEELS for ALL PURPOSES

"HELVE" — CARBON TOOL STEEL for CHISELS, PUNCHES, &c.

ROYDS WORKS AND
HARDENITE STEEL WORKS
ATTERCLIFFE ROAD, SHEFFIELD, 4

Export Department
THE HARDENITE STEEL COMPANY LIMITED

Telephone: Sheffield 22131
Telegrams: Shafting, Sheffield, 4

ARB DGI APPROVED

ELECTRO HEAT TREATMENTS LTD.

BULL LANE WEST BROMWICH
Telephone WES 0584—0758

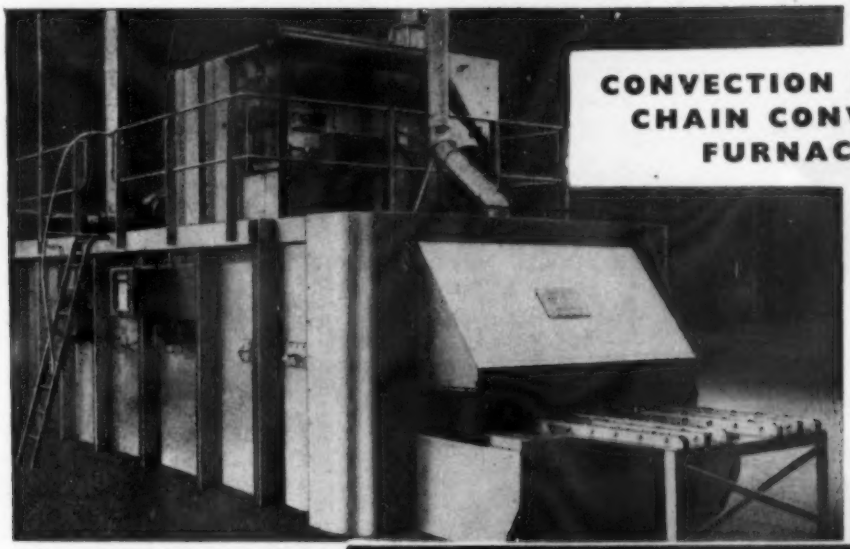
BRIGHT ANNEALING
Copper and steel pressings, bolts, strip, etc.

BRIGHT HARDENING
Bolts, springs, etc. Also large components up to 3 ft.

CASE HARDENING
Carbonitriding and Gas Carburizing up to 4 ft. 6 in. High frequency up to 10 kVA.

LIGHT ALLOYS
Solution and precipitation up to 10 ft.

We specialize in the use of controlled atmospheres for all heat treatment. 100 ton weekly capacity - Laboratory supervision - Local deliveries



CONVECTION HEATED CHAIN CONVEYOR FURNACES

Suitable for Aluminium Billet and Slab Heating, tempering of still products and other processes up to 650°C.

DOWSON & MASON LTD

ALMA WORKS LEVENSHULME MANCHESTER

Telephone: HEATON MOOR 625! (5 lines) Telegrams: Gasify, Manchester 19

IGI GROUP

STAINLESS STEEL HEAT RESISTING

ABRASIVE RESISTING HEAT & ABRASIVE RESISTING

CYANIDING POTS
CASE HARDENING BOXES
CAST IRON, BRASS, GUN METAL
PHOSPHOR BRONZE, ALUMINIUM etc.

JOFO

CHROMIUM STEELS MAGNET STEELS

HIGH SPEED TOOL, DIE & SPECIAL ALLOY STEELS also STAINLESS STEEL ROAD LINES, STUDS & SIGNS . . . .

HIGHLY ALLOYED STEEL CASTINGS

'JOFO' castings are available in a wide range of qualities

From a few ozs up to 25 cwts each

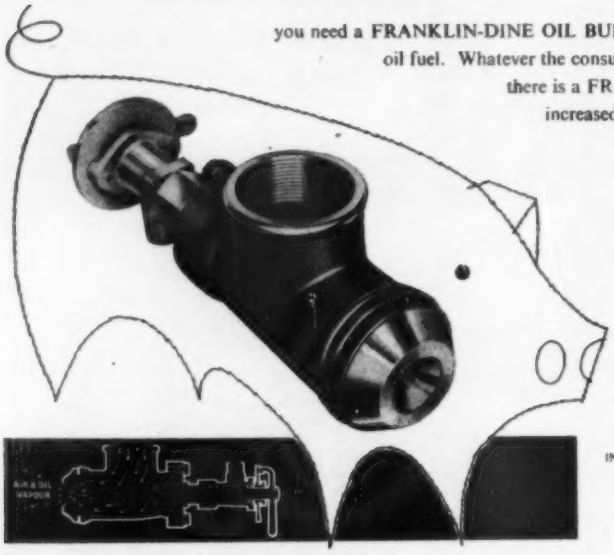
M.O.S. approved inspection facilities installed Routine X-ray control

H. Johnson Foster Ltd.

Regd. Office:
BROADFIELD RD., SHEFFIELD 8
Telephones: 52431/4
Office and Works Entrance:
AIZLEWOOD RD., SHEFFIELD 8
Foundry: Aizlewood Road, Sheffield
Machine Shops: Broadfield Road, Sheffield
London Office: Central House, Upper Woburn Place, W.C.1. (EUSton 4086)
Glasgow Office: 93 Hope Street, C.2. (Central 8342/5)

H. JOHNSON FOSTER LTD. STEELMAKERS & FOUNDERS

you don't need a piggy-bank to save!



you need a FRANKLIN-DINE OIL BURNER to achieve immediate economy in oil fuel. Whatever the consumption, from ¼th to 150 gallon per hour there is a FRANKLIN-DINE OIL BURNER to give increased oil economy at lower maintenance cost. Write to-day for full particulars.

FRANKLIN

for all furnaces

Manufacturers of
INDUSTRIAL FURNACES AND OIL BURNING EQUIPMENT FOR ALL PURPOSES

FRANKLIN FURNACE CO. LTD.
BAKER STREET, SPARKHILL, BIRMINGHAM, 11.
Phone: VICtoria 2579

INDEX TO ADVERTISERS

Abbey Heat Treatments Ltd. .. 32
A.C.E.C. 21
A.E.I.—Birlec Ltd. .. .. .. —
Alldays & Onions Ltd. 33
Andrews, Thos., & Co. Ltd. 34
Annealers Ltd. 31

Barlow-Whitney Ltd. .. .. .. —
Birlec-Efco (Melting) Ltd. 22
Brayshaw Furnaces Ltd. 8
Briggs Bros. (Engineers) Ltd. .. 32
British Furnaces Ltd. 16
British Iron and Steel Federation .. —
British Resistor Co. Ltd., The .. —
Broadbent, Thos., & Sons Ltd. .. 15
Burbidge, H., & Son Ltd. .. .. —

Calorizing Corporation of Great Britain Ltd. (The) .. .. .. —
Coventry Machine Tool Works Ltd. 6
Cronite Foundry Co. Ltd. (The) .. —

Doncaster, Daniel, & Sons Ltd. .. —
Dowding & Doll Ltd. .. .. .. —
Dowson & Mason Ltd. 35

Efco Furnaces Ltd. 7
Electrical Development Assn. .. 25
Electroflo Meters Co. Ltd. .. .. —
Electro Heat Treatments Ltd. .. 34
Engelhard Industries Ltd. .. .. —
Engineering Heat-Treatments (Manchester) Ltd. 31
English Electric Co. Ltd. .. .. —
English Steel Corporation Ltd. .. —
E.N.V. Engineering Co. Ltd. .. .. —
Ether Ltd. 12, 13

Eumuco (England) Ltd. 18

Firth, Thos., & John Brown Ltd. .. 17
Firth-Derihon Stampings Ltd. .. —
Flame Hardeners Ltd. .. .. —
Foliac Graphite Products Ltd. .. —
Franklin Furnace Co. Ltd. 36

Garringtons Ltd. .. .. .. —
Gas Council 38
General Electric Co. Ltd. .. .. —
General Refractories Ltd. .. .. —
Gibbons Brothers Ltd. .. .. —
Gibbons (Dudley) Ltd. 4
Granby, Paul, & Co. Ltd. 37
Graphoidal Developments Ltd. .. 32
G.W.B. Furnaces Ltd. 14

Hedin Ltd. .. .. —
Herbert, A., Ltd. .. .. .. —
Hydraulic Engineering Co. Ltd. .. —

I.C.I. Ltd. .. .. —
Incandescent Heat Co. Ltd. (The) .. 19

Johnson Foster, H., Ltd. 35

Lafarge Aluminous Cement Co. Ltd. —
Langley Forge Co. Ltd. .. .. —
Leeds & Northrup Ltd. .. .. —

Massey, B. & S., Ltd. 2
Mellowes & Co. Ltd. 34
Metalectric Furnaces Ltd. .. .. —
Mond Nickel Co. Ltd. .. .. —
Morganite Crucible Ltd. 5
Morgan Refractories Ltd. .. .. —
Morris, B. O., Ltd. .. .. .. —

National Machinery Co. (The) .. 9
Newall, A. P., & Co. Ltd. .. .. —

Premier Oil Burners Ltd. 33
Priest Furnaces Ltd. 3

Shell-Mex & B.P. Gases Ltd. .. .. —
Siemens-Schuckert (G.B.) Ltd. .. —
Smethwick Drop Forgings Ltd. .. —
Somers, Walter, Ltd. 1
Stein, John G., & Co. Ltd. .. .. —
Stordy Engineering Ltd. .. .. —

Thermic Equipment & Engineering Co. Ltd. 10
Thompson, John, (Dudley) Ltd. .. —
Thompson, Joseph, (Sheffield) Ltd. .. —
Thompson L'Hospied & Co. Ltd. .. —

United Steel Companies Ltd. .. —

Vaughan, Edgar, & Co. Ltd. 31

West, E. & A., Ltd. 20
West Instrument Ltd. .. .. —
Wickman Ltd. 11
Wiggin, Henry, & Co. Ltd. 27
Wild-Barfield Electric Furnaces Ltd. 24
Wilkins & Mitchell Ltd. .. .. —
Workington Iron & Steel Co. .. —

Published by the Proprietors, INDUSTRIAL NEWSPAPERS (FUEL AND METALLURGICAL), LIMITED, John Adam House, 17/19 John Adam Street, Adelphi, London, W.C.2, and Printed in Great Britain by F. J. PARSONS, LTD., London and Hastings. Registered for transmission by Canadian Magazine Post.

Fast

Simple

Reliable!

The *new* LASCO High-Speed Hammer with short stroke and extra heavy tup, specially suitable for multi-impression work. With single stroke or continuous operation control.

✻ *Convert your old board, belt, or steam hammer by fitting a modern LASCO driving head.*

Lasco **HIGH-SPEED ELECTRO-HYDRAULIC DROP-HAMMER** Type KH

PG

PAUL GRANBY & CO. LTD.

39 VICTORIA STREET · WESTMINSTER · LONDON · S W 1

Telephone: ABBEY 5338 Telegrams: POWAFORGE, SOWEST, LONDON Cables: POWAFORGE, LONDON

metal atment

Vol. 28 : No. 183 MAY, 1961 Price 2/6

Get Going with GAS

THE FLEXIBLE FUEL SERVICE

Get going with *Gas*, whatever the job. *Gas* gives fierce or gentle *Heat*; fast or slow *Heat*; flexible *Heat*; fully automatic *Heat* ... but always clean, economic and reliable *Heat*. With the benefits of the industry's research and its free technical advisory service, enjoy confidence with *Gas*.

ISSUED BY THE GAS COUNCIL